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STRUCTURES AND DYNAMICS DIVISION RESEARCH AND TECHNOLOGY PLANS FOR FY 1988 AND ACCOMPLISHMENTS FOR FY 1987

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

RESEARCH AND TECHNOLOGY PLANS FOR FY 1988 AND ACCOMPLISHMENTS FOR FY 1987

BY

KAY S. BALES

SUMMARY

The purpose of this report is to present the Structures and Dynamics Division's research plans for FY 1988 and accomplishments for FY 1987. The work under each branch is shown by RTR Objectives, FY 1988 Plans, Approach, Milestones, and FY 1987 Accomplishments. Logic charts show elements of research and rough relationship to each other. This information is useful in program coordination with other government organizations in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. The Structures Directorate includes Structures and Dynamics Division, Materials Division, Loads and Aeroelasticity Division, and Acoustics Division. The Structures and Dynamics Division consists of four branches as shown on figure 2. There have been some significant changes in the organizational structure of the Division. For FY 1988, Dr. Michael F. Card is on TDY to NASA Marshall Space Flight Center; Mr. Charles P. Blankenship is Acting Chief, Structures and Dynamics Division; and Dr. Clarence P. Young, Jr., was appointed Assistant Chief, Structures and Dynamics Division. Mr. John A. Tanner was selected Head, Impact Dynamics Branch; Dr. W. Jefferson Stroud was selected Assistant Head, Structural Mechanics Branch; and Dr. Robert J. Hayduk was selected Assistant Head, Structural Dynamics Branch.

FUNCTIONAL STATEMENT

The Division conducts analytical and experimental research to achieve structures which meet functional requirements of advanced atmospheric and space flight vehicles. Provides experimental data and analytical methods for predicting stresses, deformations, structural strength, and dynamic response. Investigates interaction of structure with propulsion and control systems, landing dynamics, crash dynamics, and resulting structural response. Develops and evaluates structural configurations embodying new material systems and/or advanced design concepts for general application and for specific classes or new aerospace vehicles. Develops advanced structural analysis methods and computer programs. Uses a broad spectrum of test facilities and develops new research techniques. Test facilities include the Structures and Materials Laboratory, Structural Dynamics Research Laboratory, Impact Dynamics Research Facility and the Aircraft Landing Dynamics Facility. Data are also obtained and analyzed from flight investigations.

TABLE OF CONTENTS

I ORGANIZATION CHARTS

LANGLEY RESEARCH CENTER

DIRECTOR
Richard H. Petersen
DEPUTY
Paul F. Holloway
ASSOCIATE
Sidney F. Pauls

CHIEF SCIENTIST
R. W. Barnwell
- Research Quality/Content
- University Programs

AERONAUTICS
R. V. Harris, Jr.
H. L. Beach, Jr.
- Aerodynamics
- Propulsion Integration
- Operating Problems
- Aeronautical Systems Studies

STRUCTURES
C. P. Blankenship
- Structures & Materials
- Aeroelasticity
- Acoustics

FLIGHT SYSTEMS
J. F. Creedon
- Controls & Guidance
- Flight Management
- Information Systems
- Electromagnetics

SPACE
R. R. Nunamaker
- Aerothermodynamics
- Energetics
- Atmospheric Sciences
- System Studies
- Shuttle & Space Station Support

MANAGEMENT OPERATIONS
J. F. Stokes
- Administrative Support
- Resources Management

SYSTEMS ENGINEERING & OPERATIONS
R. L. Swain
R. T. Wingate
- Engineering Support
- Fabrication
- Facility Operations
- Reliability/Quality Assurance
- Safety

ELECTRONICS
W. D. Mace
- Instrumentation
- Computer/Simulator Support
- Remote Sensing Technology
- Project Management

AUGUST 1987

Figure 1.

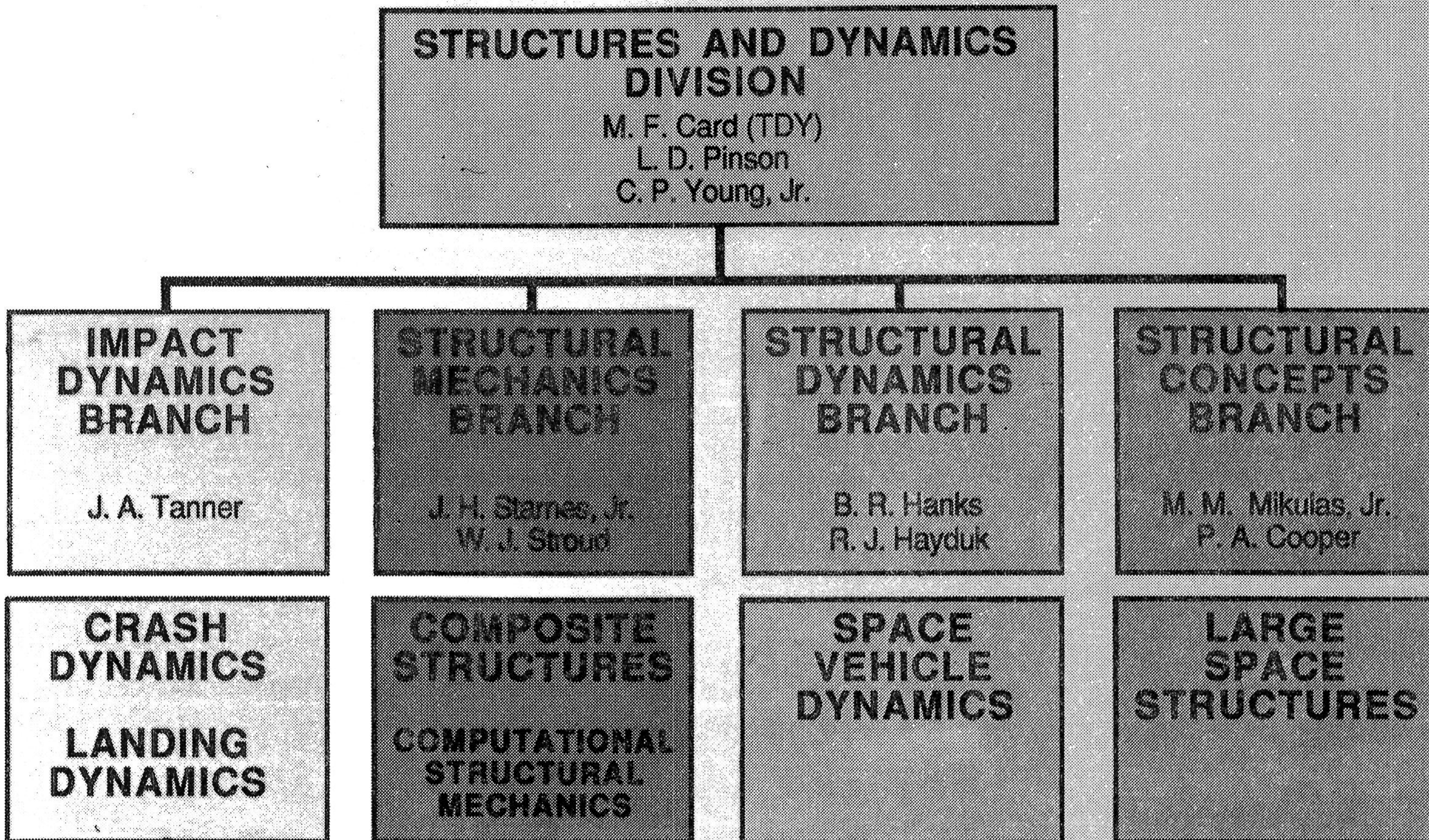

STRUCTURES AND DYNAMICS DIVISION
M. F. Card (TDY)
L. D. Pinson
C. P. Young, Jr.
IMPACT DYNAMICS BRANCH
J. A. Tanner
STRUCTURAL MECHANICS BRANCH
J. H. Starnes, Jr.
W. J. Stroud
STRUCTURAL DYNAMICS BRANCH
B. R. Hanks
R. J. Hayduk
STRUCTURAL CONCEPTS BRANCH
M. M. Mikulas, Jr.
P. A. Cooper
CRASH DYNAMICS
LANDING DYNAMICS
COMPOSITE STRUCTURES
COMPUTATIONAL STRUCTURAL MECHANICS
SPACE VEHICLE DYNAMICS
LARGE SPACE STRUCTURES

Figure 2.

II FACILITIES

II FACILITIES

The Structures and Dynamics Division has four major facilities to support its research (shown in figure 3).

The Structures and Materials Laboratory equipment includes a 1,200,000 lb. capacity testing machine for tensile and compressive specimens up to 6 feet wide and 18 feet long; lower capacity testing machines of 300,000, 120,000, 100,000 and 10,000 lb. capacity; torsion machine of approximately 60,000 in.=lb. capacity; hydraulic and pneumatic pressurization equipment; and vertical abutment-type backstop for supporting and/or anchoring large structural test specimens.

The Impact Dynamics Research Facilities consist of the Aircraft Landing Dynamics Facility (ALDF) and the Impact Dynamics Research Facility. The ALDF consists of a rail system 2,800 ft. long x 30 ft. wide, a 2.0 Mlbs. thrust propulsion system, a test carriage capable of approximately 220 knots, and an arrestment system. A wide variety of runway surface conditions, ranging from dry and flooded concrete or asphalt to solid ice, can be duplicated in the track test section. In addition, unprepared surfaces such as clay or sod can be installed for tests to provide data on aircraft off-runway operations.

The Impact Dynamics Research Facility is capable of crash testing full-scale general aviation aircraft and helicopters under controlled conditions. Simulation is accomplished by swinging the aircraft by cables, pendulum-style, into the ground from an A-frame structure approximately 400 ft. long x 240 ft. high. A Vertical Test Apparatus is attached to one leg of the A-frame for drop-testing structural components.

The Structural Dynamics Research Laboratory is designed for carrying out research on spacecraft and aircraft structures, equipment, and materials under various environmental conditions, including vibration, shock, acceleration, thermal and vacuum. Equipment in the laboratory includes a 55-ft. (inside diameter) thermal vacuum chamber with a removable 5-ton crane, a flat floor 70 feet from the dome peak, and whirl tables.

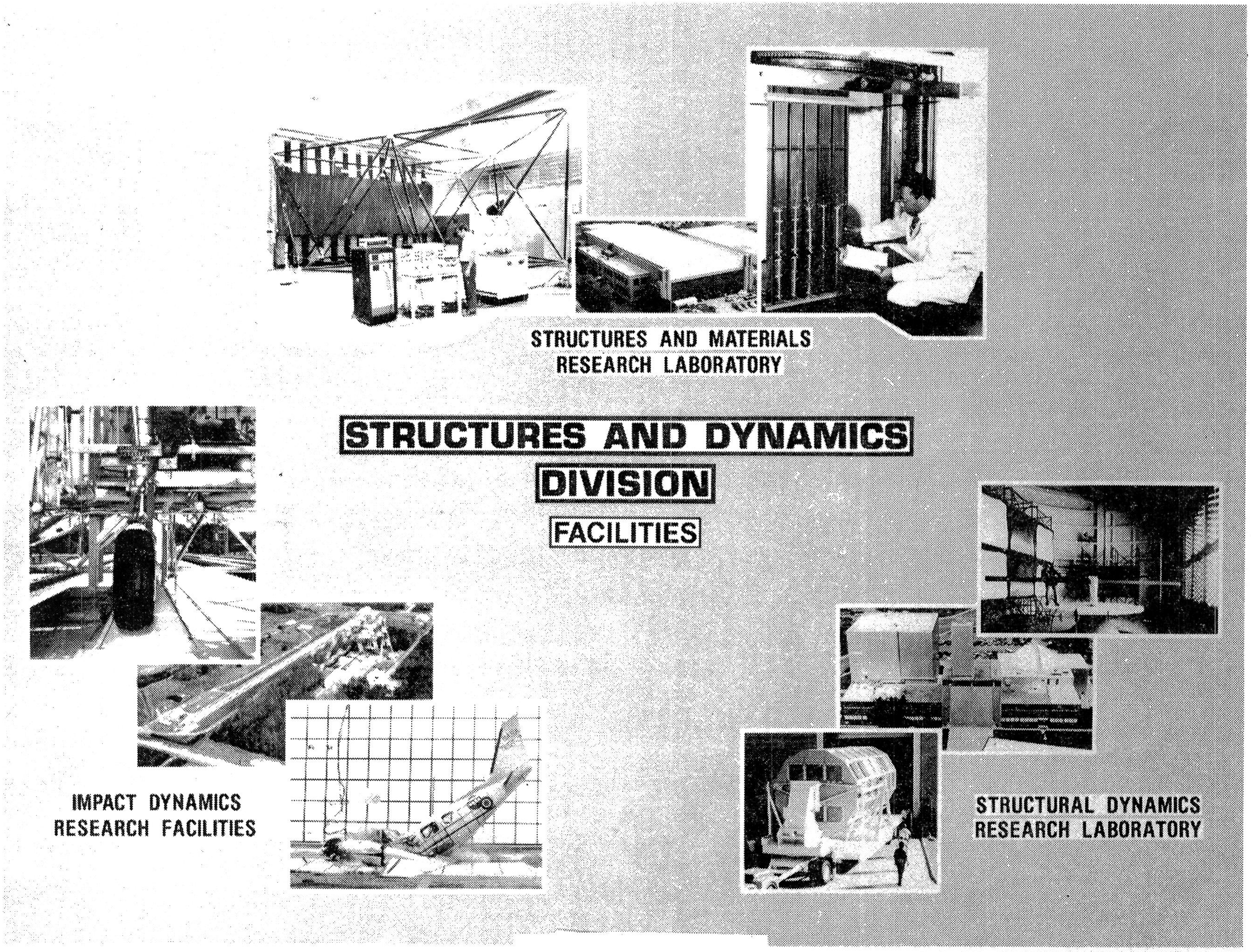
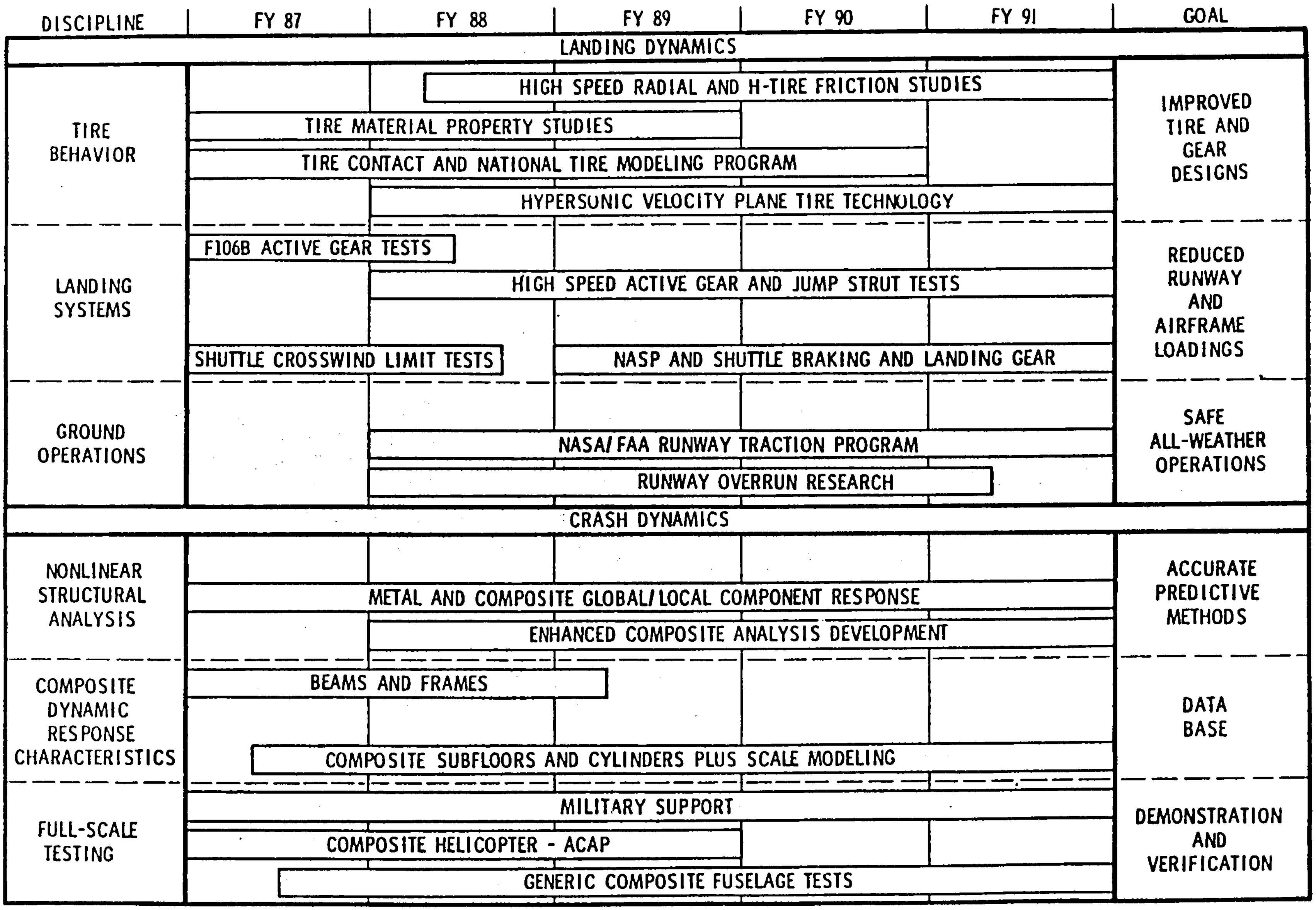

STRUCTURES AND MATERIALS
RESEARCH LABORATORY
STRUCTURES AND DYNAMICS
DIVISION
FACILITIES
IMPACT DYNAMICS
RESEARCH FACILITIES
STRUCTURAL DYNAMICS
RESEARCH LABORATORY

Figure 3.

III IMPACT DYNAMICS BRANCH

IMPACT DYNAMICS BRANCH



III IMPACT DYNAMICS BRANCH

RTR 505-63-01-11 Composite Crash Dynamics

OBJECTIVE:

To obtain a better understanding of response characteristics of generic composite components subjected to crash loading conditions and to develop analytical tools capable of predicting responses of composite structures.

FY 1988 PLANS:

- Conduct various static and dynamic tests of composite frames, subfloors, and energy absorber concepts
- Complete tests and analysis of scale model beams under impact loads
- Develop analysis tools in DYCAST for composite structures under crash loads and evaluate other crash analyses on VAX
- Support various military safety related programs through tests at Impact Dynamics Research Facility
- Develop test plans for Lear fan fuselage components

APPROACH:

In FY 1988 the main focus will be continuing the development of a data base and insights on behavior of composite components to crash loadings as well as enhancing composite analysis capability of finite element computer programs. Develop in-house test methods, procedures, and apparatus to conduct static and dynamic combined bending and axial loading tests on representative composite structural elements. Assess impact data to evaluate effect of combined axial and bending loads on global response, stiffness, and residual strength after failure, and develop new analytical techniques to predict both global and local responses. Install these new algorithms on the DYCAST computer code. Supportive contractual efforts will be used to incorporate the new analytical technique into DYCAST and to fabricate composite test components requiring special tooling.

MILESTONES:

- Conduct impact tests of composite Z-frame subfloors, December 1987
- Initiate task assignment contract to incorporate composite elements and new solution algorithms into DYCAST code for composite structures, December 1987

FY 1987 ACCOMPLISHMENTS:

- Conducted nine drop tests (six composite Z-frames and three metal) and one static test
- Published TP and AIAA papers on CID experiments

- Published SAE and American Helicopter Society papers on composite Z-frames
- Conducted composite beam impact tests (VPI&SU Graduate Student)
- Initiated composite scale impact studies (Ph.D. Dissertation)
- Initiated new composite analysis development under GWU grant
- Developed composite scale parameters under impact loads for several classes of structures (NRC Associate Dr. John Morton) (ASDM paper)

RTR 505-63-41-02 Aircraft Landing Dynamics

OBJECTIVE:

To advance the technology of aircraft landing systems with emphasis on tire mechanics, runway surface conditions, and landing gear dynamics.

FY 1988 PLANS:

- Continue development of tire modeling strategies
- Develop data base on radial and H-type aircraft tires
- Demonstrate active control landing gear technology
- Evaluate modified tires for Shuttle use
- Conduct skid and roll-on-rim tests to support Orbiter

APROACH:

In FY 1988 the main focus will be developing high-speed friction and mechanical property data base to support landing gear industry and tire analysis tools to advance tire technology. Coordinate in-house research, grants, and contracts with U.S. tire industry experimental effort to carry out National Tire Modeling Program (NTMP). Conduct detailed studies of forces and moments in static and rolling tire footprints. Develop algorithms for tire contact to include friction and rolling tire footprints. Develop algorithms for tire contact to include friction and rolling effects for NTMP and install these algorithms on Computational Structural Mechanics software testbed. Develop experimental methods for measuring material properties of tire constituents. Define wear and friction characteristics of modified Shuttle tires. Obtain frictional and mechanical property data on type H and radial ply aircraft tires.

MILESTONES:

- Present paper on mechanical properties of bias-ply and radial-ply aircraft tires at SAE AeroTech 87 meeting, October 1987
- Present paper on friction and wear characteristics of Shuttle main gear tires at SAE AeroTech 87 meeting, October 1987
- Publish paper on semianalytic finite element tire model, January 1988

- Complete Phase 1 drop tests of F106 active control landing gear and prepare for flight test, March 1988
- Publish paper on tire material property measurement techniques, June 1988
- Conduct track tests of radial-ply aircraft tires, July 1988

FY 1987 ACCOMPLISHMENTS:

- Paper on water spray patterns presented at SAE AeroTech 86 meeting
- Shuttle cornering and wear models developed and installed on Vertical Motion Simulator at ARC
- Track testing identified improved wearing compount for Orbiter tire tread
- Static tests of F-4 radial tire completed and NASA TP in editorial cycle
- Published paper on exploiting symmetries in the modeling and analysis of tires
- Published papers on B-737 and B-727 flight test programs

RTR 763-01-41-09 NASP Landing Dynamics

OBJECTIVE:

To develop the technology necessary for safe ground operations of the National AeroSpace Plane (NASP).

FY 1988 PLANS:

- Examine tire technology requirements for NASP

APPROACH:

In FY 1988 the main focus wil be initiating a program to establish landing gear technology for NASP. Conduct friction and wear studies on modified Shuttle tires to define optimum tread configuration to avoid excessive tire wear during high-speed ground operation.

MILESTONES:

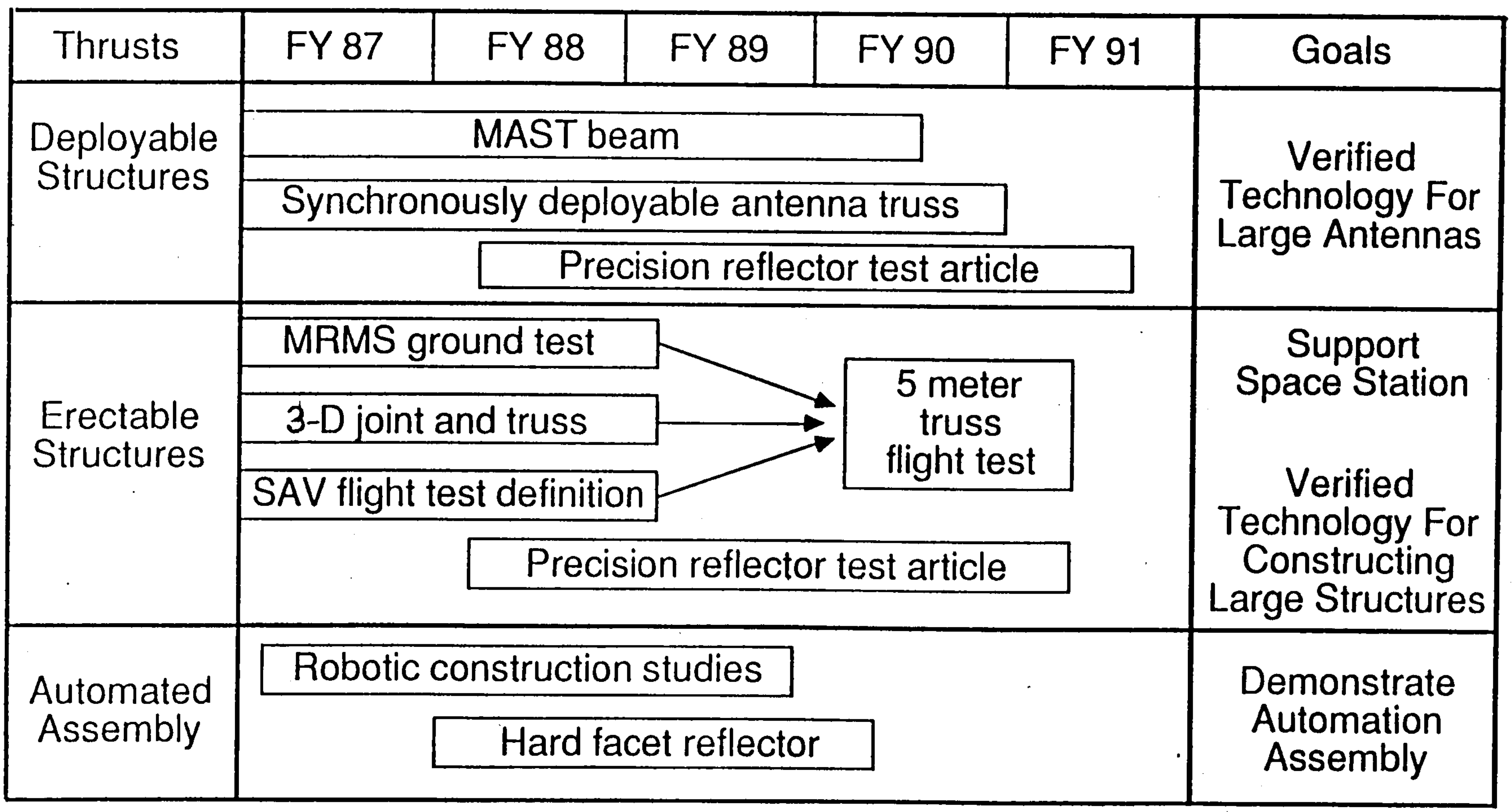
- Procure modified tires for testing, January 1988
- Initiate friction and wear studies, August 1988

FY 1987 ACCOMPLISHMENTS:

- FY 1988 new start

IV STRUCTURAL CONCEPTS BRANCH

ADVANCED SPACE STRUCTURES



IV STRUCTURAL CONCEPTS BRANCH

RTR 506-43-41-02 Advanced Space Structural Concepts

OBJECTIVE:

To develop deployable and erectable structural concepts and associated design technology for antenna and reflector structures and for Space Station.

FY 1988 PLANS:

- Deliver and install WETF (Weightless Environmental Training Facility) MRMS (Mobile Remote Manipulator System) assembly simulator at NASA JSC
- Complete 1-g and neutral buoyancy tests of MRMS/truss assembly experiment
- Complete component testing of Al-clad graphite/epoxy tubes

APPROACH:

In FY 1988 the main focus will be completion of a ground test MRMS for conducting 1-g construction tests, as well as completing Space Station construction tests in the WETF at NASA JSC. Continued emphasis will be placed on developing computer aided structures and construction design aids. A 1-inch diameter composite strut will be developed and a deployment analysis will be developed for Pactruss.

MILESTONES:

- Complete ground test MRMS hardware, November 1987
- 1-g test of MRMS, February 1988
- Complete computer simulation of Space Station construction scenario, June 1988
- Fabricate 1-inch diameter composite strut, August 1988

FY 1987 ACCOMPLISHMENTS:

- Ground test MRMS 90 percent complete
- Space Station joint developed and tested
- CAD system installed and operational
- Solar concentrator concept report completed
- SRB field joint paper written
- ETA ring study conducted

RTR 488-50-03-03 Robotic Assembly of Large Space Structures

OBJECTIVE:

- To develop technology and demonstrate potential for robotic assembly of large space structures.

FY 1988 PLANS:

- Perform a one-robot assembly of two rings of a tetrahedral truss

APPROACH:

In FY 1988 the main focus is to complete facility and begin automated assembly test. Design and develop a construction facility and associated hardware to demonstrate robotic assembly of a tetrahedral truss and use this facility as a testbed to evaluate more complex robotic assembly tasks.

MILESTONES:

- Complete system design, February 1988
- Fabricate transporter, May 1988
- Design and fabricate assembly hardware, June 1988

FY 1987 ACCOMPLISHMENTS:

- Completed conceptual design studies (RTR 506-43-41-06)

RTR 585-02-31-01 Precision Reflector Structures

OBJECTIVE:

To develop deployable and erectable structural concepts for precision reflectors.

FY 1988 PLANS:

- Develop one-inch diameter tube/joint node components for precision segmented reflector erectable assembly study
- Develop Pactruss concept for precision segmented reflector deployable assembly study

APPROACH:

In FY 1988 the main focus will be to design a Pactruss and fabricate a 7-bay test article. Deployment techniques will be studied and one concept will be fabricated for testing. A one-inch erectable joint will be designed and fabricated for testing.

MILESTONES:

- Develop 20-meter reflector truss geometry design, November 1987
- Develop 20-meter reflector Pactruss design, January 1988
- Develop 20-meter reflector erectable truss design, January 1988
- Fabricate 7 bays of Pactruss, September 1988
- Fabricate 7 bays of erectable truss, September 1988

FY 1987 ACCOMPLISHMENTS:

- FY 1988 new start

RTR 906-55-62-01 Flight Experiment Definition

OBJECTIVE:

To provide integration support for the 5-meter erectable flight experiment with the Space Shuttle.

FY 1988 PLANS:

- Support formulation of station assembly verification flight test

APPROACH:

In FY 1988 the main focus is to perform a ground test assembly demonstration of a full-scale Space Station truss. An in-house effort will be conducted to integrate the 5-meter erectable flight experiment the the Space Shuttle system. The study will include hardware integration, EVA handling considerations, pallet mountings, and instrumentation integration. Detailed drawings of the hardware will be made and l/8-scale and full-scale mock-ups will be built to verify the designs.

MILESTONES:

- Complete design of assembly fixture, June 1988
- Complete assembly definition, September 1988

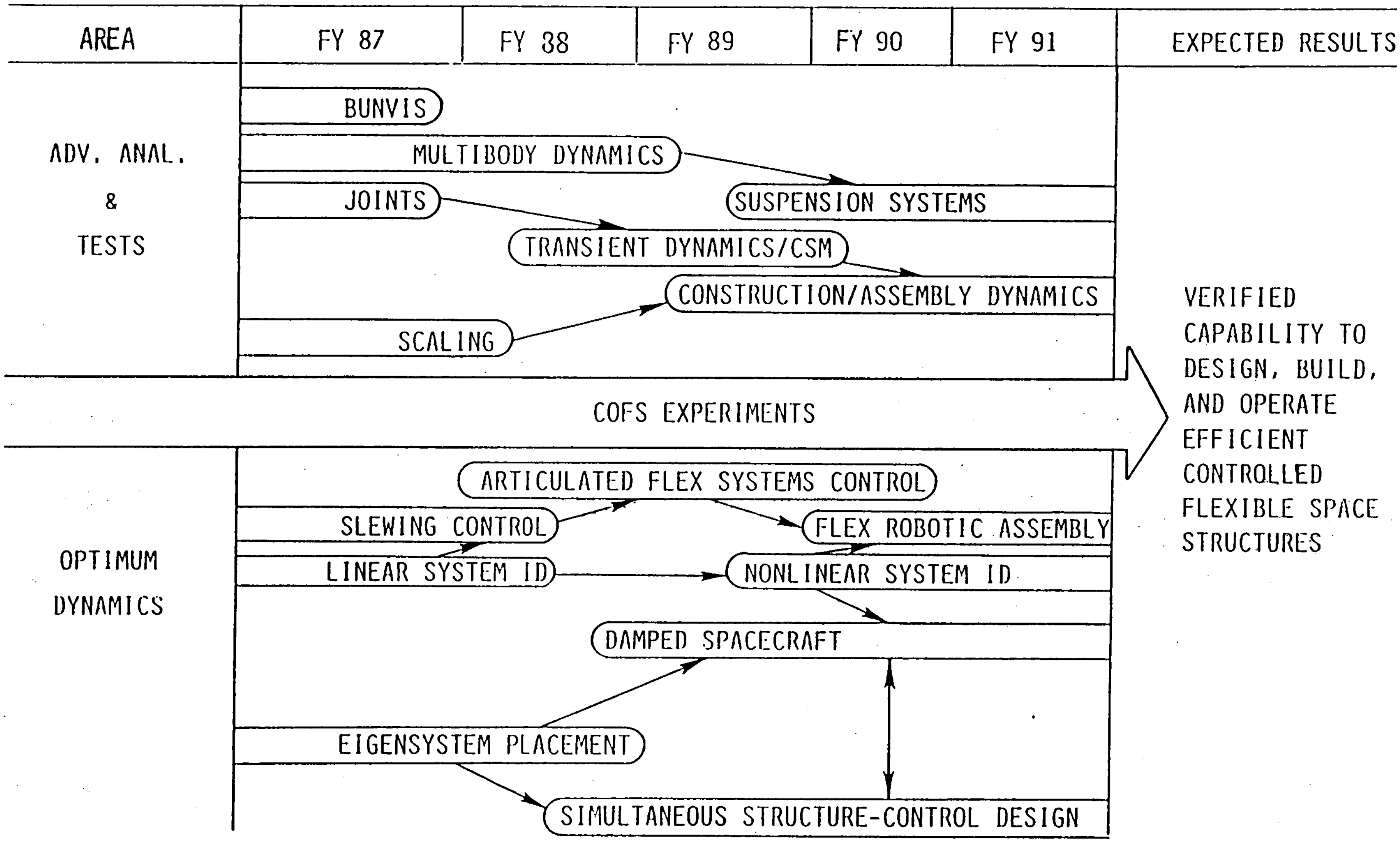
FY 1987 ACCOMPLISHMENTS:

- Completed SAVE II concept study
- Presented SAVE II at NASA JSC

V STRUCTURAL DYNAMICS BRANCH

STRUCTURAL DYNAMICS BRANCH

ACTIVITIES



V STRUCTURAL DYNAMICS BRANCH

RTR 585-01-21-01 Optimum Dynamic Performance

OBJECTIVE:

To accomplish validated capability for design/analysis of reliable multi-component maneuvering for large flexible space structures with optimal dynamic performance.

FY 1988 PLANS:

- Design 5-body articulated structure slewing control experiment
- Continue integrated design of controlled structures:
  - Eigen system placement
  - COFS I control algorithms (with IMAT)
  - Simultaneous structure-control design

APPROACH:

In FY 1988 the main focus will be theoretical development and experimental verification of robust vibration suppression designs for large angle maneuvers of a multi-body dynamic system. An articulated flexible arm will be designed, built, analyzed and tested for verification of previously developed techniques. The actuators currently used will be replaced by new actuators with minimum backlash to quantify the effect of actuator dynamics to maneuver dynamics designs. Studies of optimal projection filters for parameter and state estimates will be continued. Developments of reliable (robust) designs for eigenvalue and eigenvector placements will be continued to include the effect of actuator and sensor locations. Study of extendable structural links for vibration suppression will be continued.

MILESTONES:

- Initiate hardware designs for the articulated flexible arm experiment, November 1987
- Initiate basic concepts of system identification algorithms for nonlinear systems, December 1987
- Initiate basic concepts in frequency domain for robust vibration suppressor design, March 1988

FY 1987 ACCOMPLISHMENTS:

- Three-flexible-body multi-axis maneuvering demonstrated
- Single-mode projection filter for modal parameter identification and state estimation developed
- Frequency-domain eigensystem realization algorithm developed
- Technique for eigenvalue and eigenvector placements with robustness developed
- Maneuver dynamics design which can learn from past performance developed and ready for experimental verification

RTR 585-01-21-02 Advanced Spacecraft Dynamics

OBJECTIVE:

To develop and validate methods for predicting and experimentally verifying the coupled structural dynamics and control of multi-body space structures with flexible components, interfaces, dissipative mechanisms, and large amplitude responses.

FY 1988 PLANS:

- Initiate COFS III test methods development on phase-zero model
- Demonstrate initial 3-D LATDYN capability on sample problems

APPROACH:

In FY 1988 the main focus will be coding, checkout, and application of three-dimensional computerized simulation of controlled dynamics of multi-body flexible space structures as encountered in deployment, slewing, and robotic arm manipulation. Included in this thrust is the development of improved modularized transient algorithms for concurrent computing, and realistic verified models for joint and interface damping mechanisms. Test suspension methods for large space structures will be studied analytically and experimentally.

MILESTONES:

- 3-D LATDYN multi-body simulation research code initial operational capability, March 1988
- Validation and application of PANTA (Parallel Algorithm for Nonlinear Transient Analysis), March 1988
- Establish suspension and test techniques for space station subscale testing using COFS III Phase-Zero model, April 1988

FY 1987 ACCOMPLISHMENTS:

- COFS I baseline configuration deployment successfully predicted and compared with contractor results
- 3-D LATDYN formulation complete and 3-D contract initiated for computer implementation
- Preliminary dynamic behavior of suspended dual keel space station subscale model established

RTR 585-01-11-06 Beam Dynamics Ground Tests

OBJECTIVE:

To validate ground test technology, conduct tests necessary to demonstrate flight readiness, and validate analytical models of the Mast flight system.

FY 1988 PLANS:

- Complete Mini-Mast tests and analyses

APPROACH:

In FY 1988 the main focus is conceptual design of a suspension system for ground testing the Mast flight system and the validation of the Mini-Mast analytical model. Analytical methods for including joint characteristics and suspension dynamics in a global dynamic model will be evaluated. Data acquisition techniques will be incorporated with modal analysis software to facilitate identification of structural parameters from ground tests. Procurement of two scale models of the flight Mast will be initiated in a joint NASA/USAF program.

MILESTONES:

- Complete analysis of Mini-Mast joints, December 1987
- Release RFP for scale models, February 1988
- Define candidate suspension for flight beam, April 1988
- Complete model validation of Mini-Mast, June 1988

FY 1987 ACCOMPLISHMENTS:

- Mini-Mast deployed in Bldg. 1293B tower
- Completed Mini-Mast static tests
- Completed Mini-Mast dynamic tests

RTR 585-01-31-02 COFS III Technology - Test Methods

OBJECTIVE:

To develop mathematical models and a ground test approach for testing COFS III scale models.

FY 1988 PLANS:

- Initiate COFS III Test methods development on phase-zero model

APPROACH:

In FY 1988 the main focus is development of mathematical models and test concepts for the COFS III Phase-Zero model. Mathematical models of the COFS III Phase-Zero model will be developed. These models will be used to define suspension motion and force requirements using methods developing in the base program. Building 1293A high-bay area will be prepared for testing a geometric model of the Space Station.

MILESTONES:

- Complete assembly of initial geometric model, March 1988
- Initiate tests with simple suspension and instrumentation, June 1988

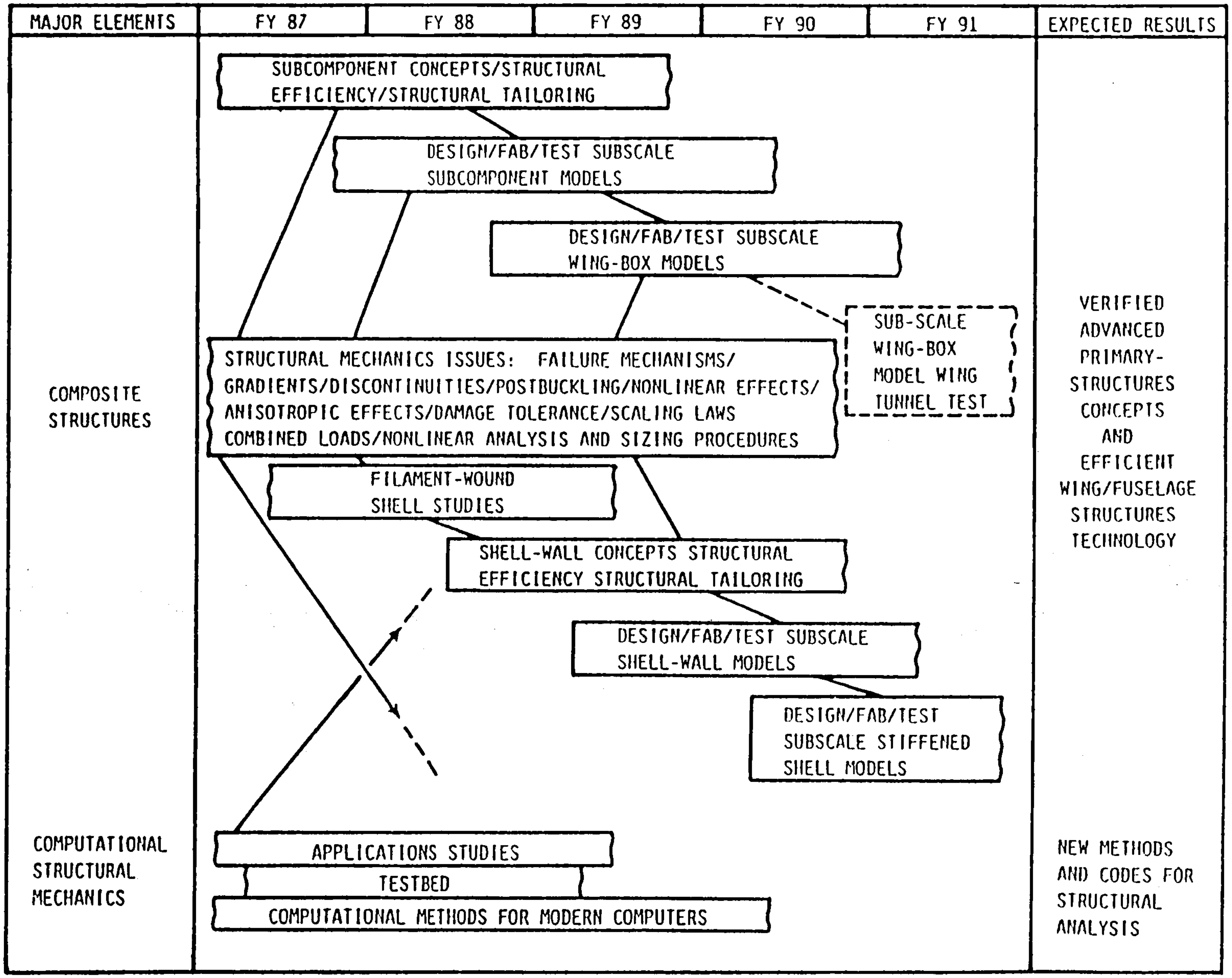
FY 1987 ACCOMPLISHMENTS:

- Initial tests of 1/4-scale prototype truss completed
- Tests of preliminary joints and tubes
- Completed model definition study
- Initiated procurement of geometric (Mero-Form) model
- Initiated test issues study contract
- Released Phase A conceptual design SOW (Statement of Work)
- Contracted scale model joint fabrication

VI STRUCTURAL MECHANICS BRANCH

STRUCTURAL MECHANICS

COMPOSITE STRUCTURES



VI STRUCTURAL MECHANICS BRANCH

RTR 505-63-01-08 Mechanics of Composite Structures

OBJECTIVE:

To develop mechanics technology required for verified design of structurally-efficient, damage-tolerant advanced-composite airframe structural components and to formulate advanced analysis methods to predict static and dynamic nonlinear response and ultimate strength of composite structures.

FY 1988 PLANS:

- Continue studies of local gradients, local damage, discontinuities and eccentricities on new composite structural subcomponents
- Conduct analytical studies of cross-sectional warping and nonlinear modal interaction for stiffened composite plates
- Complete filament-wound case and ETA ring analyses for SRB

APPROACH:

In FY 1988 the main focus is on anisotropic plate and shell analyses and error analysis for nonlinear structural analysis. Structural mechanics issues of advanced concepts for composite structural components will be studied analytically and experimentally. Mechanical and pressure loads representative of wing and fuselage components will be considered. Methods will be developed for predicting strength, stiffness, buckling and postbuckling behavior of composite components including those with local gradients, discontinuities, eccentricities and damage. Procedures will be developed that predict large deformations and 3-D stresses in flat and curved composite panels. Failure mechanisms wil be identified and analytical models for predicting failure will be developed and compared with failure criteria.

MILESTONES:

- Initiate study of cross-sectional warping for stiffened composite compression panels with nonlinear behavior, October 1987
- Initiate studies of anisotropic plate and shell behavior, November 1987
- Complete analyses of filament-wound SRB shell and effect of ET attachment rings on SRB behavior, December 1987
- Complete development of error analysis for nonlinear plates using recontinuization method and extend method to include effects of geometric imperfections, March 1988
- Complete test-analysis correlation of stiffened filament-wound cylinder and heavily-loaded side-of-body wing joint, April 1988

- Complete development of equivalence transformation with multiple modes and make operational in STAGS, September 1988
- Develop analysis capability for curved composite panels with transverse stiffeners for VICON and initiate implementation into PASCO, September 1988

FY 1987 ACCOMPLISHMENTS:

- Failure analysis of compression-loaded multi-directional laminates verified and additional analytical refinements formulated
- Conducted detailed shell-of-revolution analyses of SRB clevis-tang field joint with and without capture tang and identified effects of tolerances on joint performance
- Conducted shell-of-revolution analysis of filament-wound SRB transition section and determined interlaminar stress trends
- Developed structural analysis model of filament-wound SRB ST-2A test and initiated nonlinear analysis
- Studied effects of transverse-shear deformations on composite shear webs with postbuckling behavior and determined that transverse-shear effects are more important for compression panels than for shear webs
- Multimode solution procedure developed for STAGS equivalence transformation and being verified with simple examles.
- Failure analysis of strength-critical compression-loaded laminates with dropped plies shown to be conservative and need for improved failure analysis identified.
- Effects of stacking sequence on postbuckling behavior of compression-loaded curved composite panels identified. Stiffer laminates have less postbuckling strength reduction than softer laminates

RTR 505-63-01-09 Advanced Composite Structural Concepts

OBJECTIVE:

To develop verified composite structural concepts and design technology needed to realize the improved performance, structural efficiency, and cost-effective advantages offered by new material systems and fabrication procedures for advanced-composite airframe primary structural components.

FY 1988 PLANS:

- Continue development and evaluation of new structurally-efficient composite structures concepts
- Continue studies of structural tailoring and interleaving for stiffened panels and high-aspect-ratio wing box concepts

- Continue studies of the effects of filament winding and anisotropic effects on composite shell structures

APPROACH:

In FY 1988 the main focus is on evaluating structurally-tailored wing-box subcomponent design concepts and thermoplastic panel concepts. Advanced structural concepts for primary structures applications will be developed and evaluated for structural efficiency, damage tolerance and improved performance. The effects of design constraints, such as those imposed by aeroelastic tailoring and laminar flow requirements, will be included in the design of new structural concepts for aircraft components. Mechanical and pressure loads representative of wing and fuselage structural components will be considered. Structural mechanics issues peculiar to these new design concepts will be studied and selected concepts evaluated experimentally.

MILESTONES:

- Fabricate two hat-stiffened panels from comingled graphite-PEEK thermoplastic, October 1987
- Initiate optimum design studies of geodesic compression panels with damage-tolerance constratins, November 1987
- Document SRB ET attachment ring joint analyses, December 1987
- Complete design and evaluation of advanced concepts for high-aspect-ratio aeroelastically-tailored transport wings and define test specimens, February 1988
- Evaluate effects of cross-over patterns on filament-wound laminate strength for panels with cutouts and impact damage, June 1988
- Complete experimental study of effects of cutouts and impact damage on postbuckling strength of composite shear webs, July 1988
- Conduct design and analysis studies of advanced-concept tapered spars and initiate specimen fabrication, July 1988
- Conduct analytical and experimental correlation of structurally-tailored optimized stiffened panel and develop optimum design of stiffened panels with holes, August 1988
- Complete experimental evaluation of filament-wound and pultruded multiwall panels, August 1988
- Evaluate effects of stiffener run-out on compression strength of composite panels, August 1988
- Evaluate new thermoplastic material forms for application to advanced structural concepts, September 1988
- Fabricate C-130 center wing box technology integration box beam, September 1988

FY 1987 ACCOMPLISHMENTS:

- Preliminary design of geodesic stiffened compression panel evaluated experimentally and shown to be damage tolerant
- Multi-circuit filament-wound plates with holes determined to have lower compressive strength than single-circuit filament-wound plates
- Fluted-core panels with two layers shown to be less structurally efficient than panels with one fluded core layer
- Geodesic stiffened wing spar fabricated for C-130 center wing box and specimen to be tested to evaluate performance
- Simultaneous analysis and design methodology developed for buckling problems and demonstrated for large-scale nonlinear problems
- Preliminary design procedure for structurally-tailored high-aspect-ratio forward-swept wing developed and baseline design obtained
- Protection and detection system for low-speed impact damage developed and being evaluated by testing
- Multi-wall panel subcomponents manufactured by filament winding and pultrusion; specimens being prepared for testing
- Impact-damage tests on foam-core sandwich components for C-130 wing box indicate significant core damage due to impact damage and reduced strength
- Graphite-epoxy 3-stiffener wing plank for C-130 center wing box pultruded and being prepared for testing; wing spar concepts fabricated and being evaluated by tests. Blade-stiffened IM7/8851-7 graphite-epoxy cover panel being evaluated for wing box design
- High-aspect-ratio wing graphite-epoxy stiffened panels with interleaving fabricated and being prepared for damage-tolerance testing at LaRC
- Structural-efficiency study of composite wing rib concepts initiated

RTR 505-63-01-13 Structural Composites Augmentation (NRA)

OBJECTIVE:

To exploit the benefits of advanced composites for transcentury aircraft primary structural applications by providing the enabling structures technology and the necessary scientific basis for verified innovative structurally-efficient, cost-effective structural concepts.

FY 1988 PLANS:

- Evaluate proposals and award contracts/grants for NRA-87-LaRC-2 for advanced composite structural concepts

APPROACH:

In FY 1988 the main focus is on development of innovative wing and fuselage subcomponent concepts. Innovative structural concepts will be solicited by an NRA (NASA Research Announcement). Concepts that exploit the benefits of advanced composites and lend themselves to cost-effective fabrication procedures will be developed for future primary structures application and verified experimentally. Structural mechanics technologies will be developed including analysis, design and test methodologies for structurally-tailored and structurally-efficient wing and fuselage components and subcomponents with local gradients, discontinuities and complex mechanical and aerodynamic loadings. Subcomponent interaction, failure mechanisms and analyses, damage tolerance and containment, buckling, postbuckling, and other nonlinear effects for these new structural concepts will be studied analytically and experimentally. Scaling laws for composites will be developed to enable research subscale laboratory models of wing boxes and fuselage shells to be extrapolated to full-scale designs.

MILESTONES:

- Evaluate proposals for NRA-87-LaRC-2, January 1988
- Award contracts and grants for NRA-87-LaRC-2, March 1988
- Initiate design of advanced rib, spar, and cover panel concepts, April 1988
- Initiate design of structurally-tailored subscale advanced wing-box concepts, July 1988
- Initiate fabrication of subscale advanced rib, and cover panel concept specimens, September 1988
- Initiate design of advanced fuselage frame and shell-wall concepts, September 1988

FY 1987 ACCOMPLISHMENTS:

- FY 1988 new start

COMPUTATIONAL STRUCTURAL MECHANICS
FIVE YEAR PLAN

MAJOR THRUSTS	FY 87	FY 88	FY 89	FY 90	FY 91	EXPECTED RESULTS
METHODS FOR MODERN COMPUTERS	NONLINEAR GLOBAL/LOCAL, TRANSIENT DYNAMICS					ADVANCED ANALYSIS FORMULATIONS AND COMPUTATIONAL TECHNIQUES
		FAILURE ANALYSIS, THERMAL STRESSES				
			TIRE/CONTACT ANALYSIS			
	PARALLEL PROCESSING					
TESTBED	TESTBED ON MINI-SUPERCOMPUTER, SUPERCOMPUTER					EVALUATE AND TRANSFER NEW METHODS
	IMPROVE COMMAND LANGUAGE, DATA MANAGER, MODULE INTERFACES					
	METHODS DEVELOPMENT AND APPLICATIONS STUDIES					REQUIREMENTS FOR ADVANCED SOFTWARE
APPLICATIONS STUDIES	COMPOSITE PANELS					CONFIRMS ANALYSIS STRENGTHS AND DEFICIENCIES
	STRENGTH OF AEROSPACE STRUCTURES UNDER STATIC AND DYNAMIC LOADS					
	SPACE MAST, COFS					
		SPACE STATION DYNAMICS				SOLUTIONS TO DIFFICULT STRUCT. ANAL. PROBLEMS
	SRM ANALYSIS					

RTR 505-63-01-10 Computational Structural Mechanics

OBJECTIVE:

To develop advanced structural analysis and computation methods that exploit advanced computer hardware and develop common generic software system for structural analysis.

FY 1988 PLANS:

- Demonstrate capability for global/local analysis
- Select new, challenging focus problem(s)
- Demonstrate parallel methods on NAS Cray 2
- Demonstrate portability of testbed processors across several MIMD computers
- Install SPARSPAK algorithms in testbed and apply to focus problems
- Assist in SRB (Solid Rocket Booster) analysis, as necessay

APPROACH:

In FY 1988 the main focus will be on upgrading initial testbed (NICE/SPAR) and on developing analysis capability for multiprocessor computers. Methods research will emphasize procedures that exploit multiple processor computers. To aid in the methods development research a testbed system will be created. It will consist initially of software for Langley's VAX, Cyber, and FLEX computers and will be installed on NAS and other powerful multiple processor computers for evaluating methods on large, complex problems. This software system will be aimed at the computers and aerospace structural analysis problems of the 1990's and beyond.

MILESTONES:

- Assist NASA MSFC in structural analysis of SRB aft skirt, December 1987
- Couple graphics application package (e.g., PATRAN) with testbed. Demonstrate using color to clarify results of SRB analysis, February 1988
- Demonstrate capability for routine global/local analysis of composite structures, March 1988
- Demonstrate and evaluate parallel equation solvers and eigensolvers using testbed on NAS computers, April 1988
- Demonstrate parallel substructuring capability using testbed, May 1988
- Use PISCES parallel environment to demonstrate portability of testbed processors across several MIMD computers having different architectures. As part of this demonstration, evaluate parallel equation solvers and eigensolvers for structures problems having at least 4000 DOF

FY 1987 ACCOMPLISHMENTS:

- Task assignment contract for methods development, research testbed, and applications studies awarded March 1987
- Demonstrated parallel equation solver and Lanczos eigensolver using testbed-generated system matrices for CSM focus problems. Documented results in SDM presentation and NASA publication
- Installation of UNIX version of testbed on NAS under way, and expect to solve large finite element problem
- Documented SRB field joint analysis; aft skirt analysis under way
- Preliminary 2-D global/local analysis technique developed for testbed
- Developed promising parallel transient response algorithm based on new substructuring techniques. Method is unconditionally stable and shows improvements in computational speed even for single processor computers
- Developed a high-level, portable, and efficient parallel FORTRAN language (FORCE) that is running on the FLEX 20-processor computer and is being used for parallel algorithm research

VII ACCOMPLISHMENT HIGHLIGHTS

IMPACT DYNAMICS BRANCH

EFFICIENT TIRE MODELING STRATEGY DEMONSTRATED

Ahmed K. Noor, Carl M. Andersen, and John A. Tanner
Impact Dynamics Branch
Ext. 2796 December 1986
RTOP 505-63-41 WBS 25-2 Code RM

Research Objective

The objective of this research is to develop the computational structural mechanics technology necessary to analyze aircraft tire response to taxi, take-off, and landing operations.

Approach

This tire modeling strategy has three key elements: a) three-field mixed models having independent shape functions for stress resultants, strain components, and generalized displacements; b) operator splitting of some of the matrices or vectors used in the finite element model to delineate the symmetric and antisymmetric contributions to the response; and c) application of a reduction method through successive use of the finite element method and the classical Rayleigh-Ritz technique.

Accomplishment Description

One of the most challenging applications of computational structural mechanics is the modeling of aircraft tire response to ground operations. In addition to the harsh environment to which a tire is subjected, the tire itself is a composite structure composed of rubber and textile constituents which exhibits anisotropic nonhomogenous material properties as shown in the figure. These characteristics can make the cost of tire modeling prohibitive; hence, there is a need to develop modeling strategies and analysis methods to reduce this expense. The modeling strategy was used to analyze the response of an anisotropic tire subjected to uniform inflation pressure and localized loading. Operator splitting was used to generate approximation vectors for the orthotropic response, and these vectors were then used to generate the anisotropic response of the tire. The accuracy and convergence of the solutions obtained by the new strategy and the Taylor series expansion are shown in the plot. The radial displacement of the center of the tire footprint W_C predicted by the new strategy, denoted as the reduction method, and the Taylor series method are compared with the direct nonlinear finite element solution $W_{C\ Dir}$ for the same problem. The figure clearly indicates the greater accuracy and convergence rate for the new strategy.

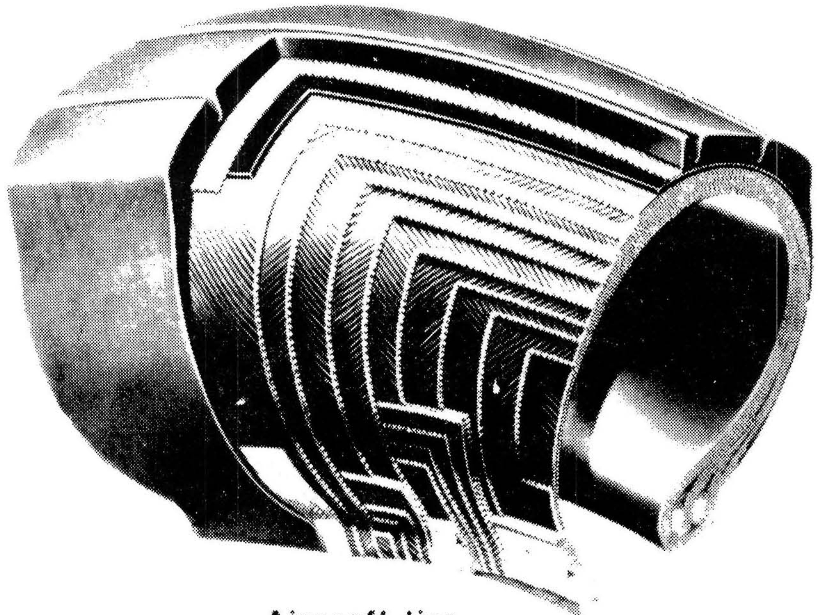
Significance

Increased accuracy and rate of convergence of this modeling strategy coupled with the ability to develop anisotropic solutions from approximation vectors generated from an equivalent orthotropic problem will greatly improve the cost effectiveness of tire analyses. This strategy could be the foundation for a family of tire analysis tools being developed as part of the National Tire Modeling Program (NTMP).

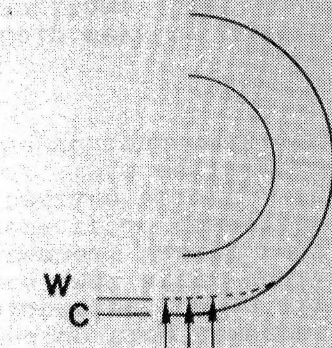
Future Plans

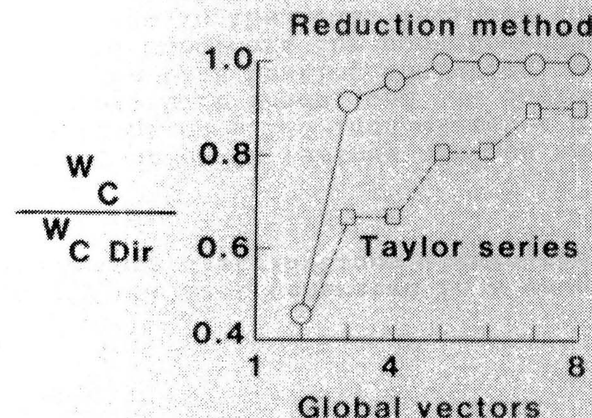
This modeling strategy is being incorporated into the contact solution algorithms under development within the NTMP. Eventually, this strategy will be installed on the multiprocessor computer system which supports the ongoing Computational Structural Mechanics (CSM) activity at Langley.

EFFICIENT TIRE MODELING STRATEGY DEMONSTRATED



Aircraft tire





HEATING IN YAWED ROLLING AIRCRAFT TIRES MODELED

Richard N. Dodge and Samuel K. Clark
University of Michigan

William E. Howell
Impact Dynamics Branch
Ext 2796 May 1987
RTOP 505-63-41
Code RM WBS 25-2

Research Objective:
The objectives of this research were to determine experimentally the heat generated in a yawed rolling aircraft tire and to develop analysis tools that predict temperature distributions within the tire carcass and tread.

Approach:
A 40 x 14, 22 ply rating aircraft tire, instrumented with thermocouples in various carcass and tread locations, has been tested under low-speed, yawed rolling conditions on a 120-inch diameter dynamometer at WPAFB. Tests were conducted over a range of inflation pressures, tire loads, and yaw angles that the tire might encounter during normal aircraft ground operations. The tire heating analytical model accounts for the damping characteristics of tire constituents and considers the nonhomogeneous characteristics of tire construction. The heat generation mechanism in the model includes the effects o cyclic stress changes in the carcass during rolling, cyclic shear stresses in the tread due to the steering effort, and frictional heating due to sliding in the tire-pavement interface.

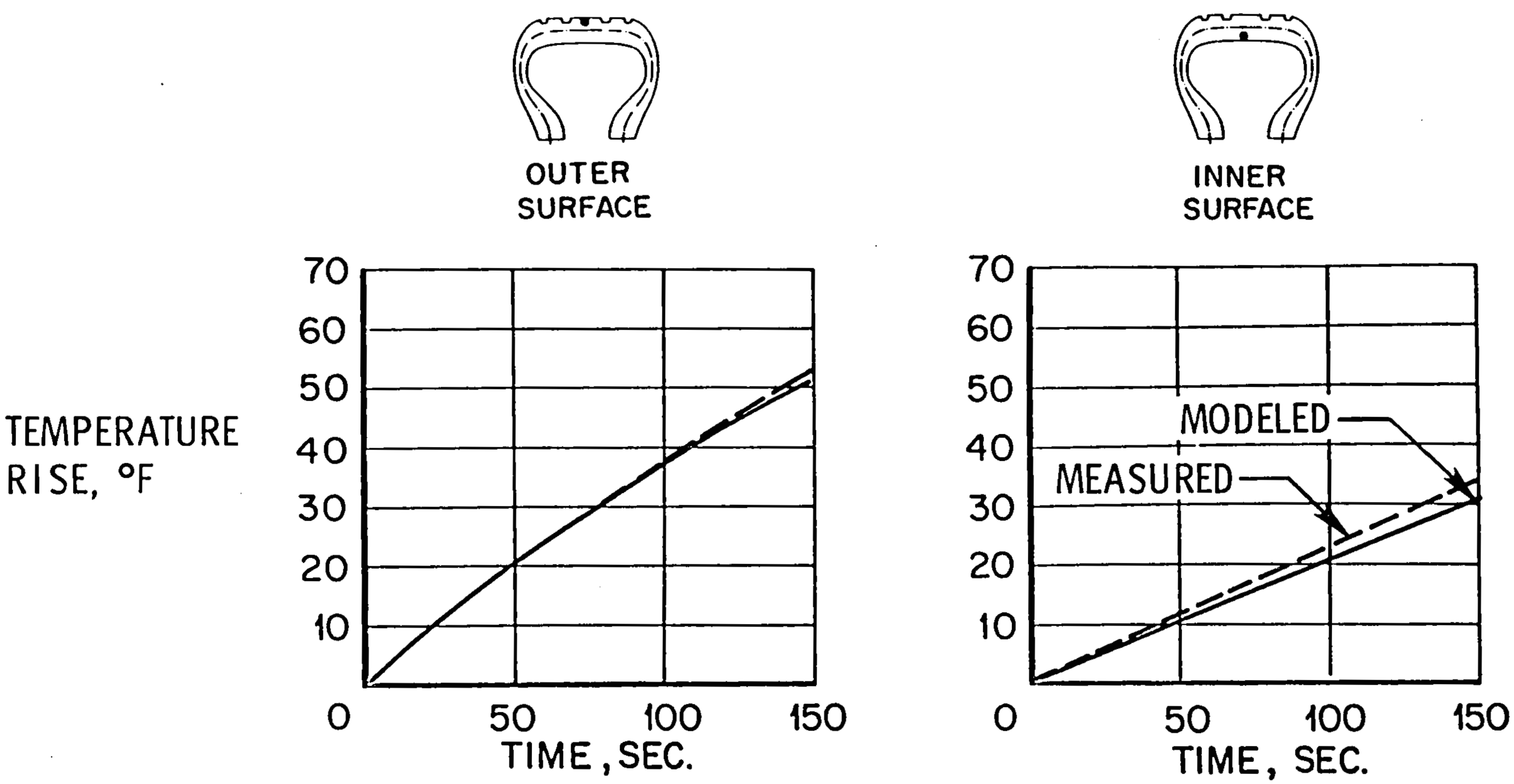
Accomplishment Description:
Excessive heating is a major cause of aircraft tire failures, and tire designers are often hampered by the lack of information that details the effects of operational conditions on tire temperature profiles. The figure shows typical measured and predicted temperature rise time histories for an aircraft tire subjected to a low-speed, yawed-rolling test condition. The data indicate that after taxiing for 150 seconds, temperatures along the tire centerline are about 20 degrees Fahrenheit warmer near the outer surface of the tread than along the inner surface of the carcass. The more rapid temperature rise in th tire tread is attributed to the frictional heating associated with the steering effort. The figure alsc shows good agreement between the measured and predicted temperature rises. This correlation suggests that the model can provide tire designers with meaningful insight into the various heat generation mechanisms that affect aircraft tire temperatures.

Significance:
This computer model provides the tire designer with an analysis tool to help develop cooler running aircraft tires. The code will be incorporated into the tire modeling algorithms under development for the National Tire Modeling Program.

Future Plans:
This heat generation model will be refined by incorporating more accurate material property data for tir constituents into the code and by using detailed information on tire footprint forces to describe the tread heating mechanism more accurately.

HEATING IN YAWED ROLLING AIRCRAFT TIRES MODELED

40 X 14 22 Ply Rating; Inflation Pressure, 140 psi;
Vertical Deflection, 2.66 in.; Yaw Angle, 3°; Speed, 17 kts



STRUCTURAL CONCEPTS BRANCH

SPACE STATION PAYLOAD SINGLE POINT TRUSS ATTACHMENT SCHEME ANALYZED TO DETERMINE ALLOWABLE PAYLOAD MASS

Mark Lake and Jon Ward
Structural Concepts Branch
Extension 2414
October 1986
RTOP 506-43-41 WBS 55-2
Code RM

Research Objective: To determine the allowable mass for a payload attached to the Space Station truss at a single truss node for a range of attachment support distances.

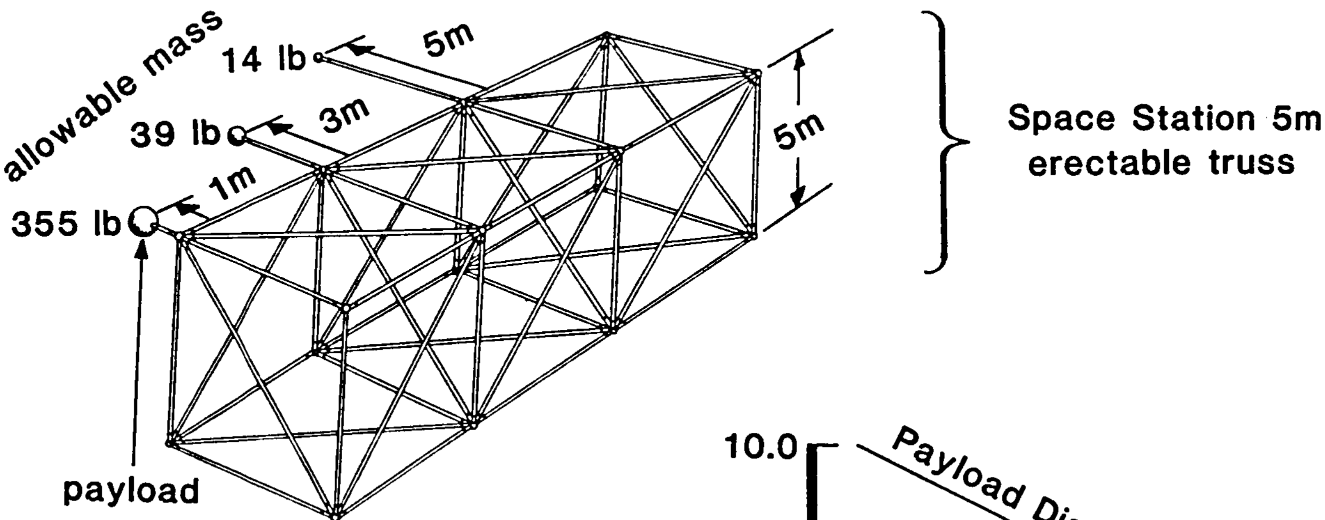
Approach: A detailed finite element model of a section of the truss was developed with a rigid member added to connect one node to a point mass representing the payload. Both the length of the member (support distance of the payload) and the mass of the payload were varied. By imposing a constraint on the value of the fundamental frequency of the payload, allowable mass vs. payload attachment height is determined.

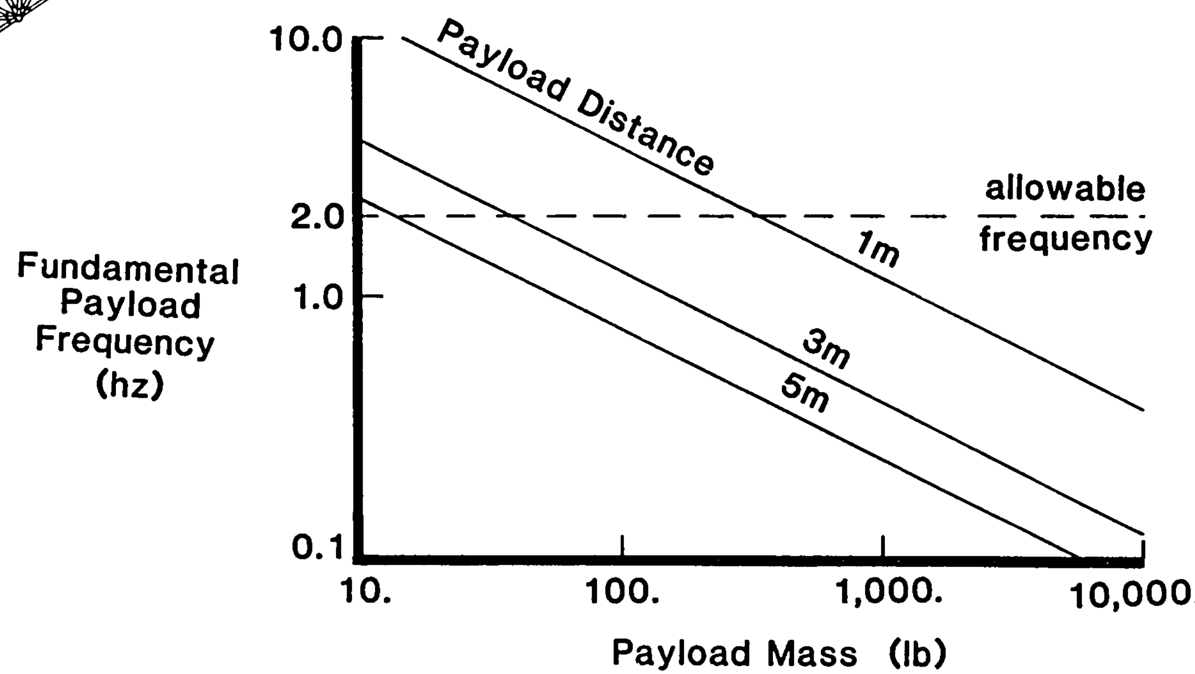
Accomplishment: On the Space Station small payloads, utility lines, and other small system items may be attached to a single structural node. Thus it is desirable to determine ranges of payload mass and single point attachment eccentricity subject to a constraint on the fundamental frequency of the payload. Based on initial axial and bending tests performed on current erectable hardware, the finite element model of the truss includes elements representing the truss joints with 30% of the stiffness of the truss struts. The attached figure shows a diagram of the proposed Space Station 5-meter truss with three payload attachment distances (1, 3, and 5-meters) and the corresponding allowable payload masses. These allowable masses were derived from the accompanying plot of fundamental frequency vs. payload mass subject to the constraint that payload vibration frequencies be greater than 2.0 Hz. The fundamental structural frequencies for Space Station are well below 2.0 Hz. Keeping payload frequencies above this somewhat arbitrary value will tend to avoid structural dynamic interactions between the structure and payload. A key result is that fairly large masses (350 lbs./160 Kg.) can be attached into a single node if they are located within one meter of the structure.

Significance: Attachment of payloads to one node only requires that motion of the payload be resisted by bending of structural truss members attached to the node. Since a truss does not carry local bending loads primarily, a requirement for single node attachment could lead to a significant structural design impact.

Future Plans: Further analyses will be conducted on this concept as information on truss joint characteristics and payload designs mature. In addition, tests on payload attachment hardware will be performed, as hardware becomes available, to verify analyses.

5 METER ERECTABLE TRUSS CAN SUPPORT LARGE PAYLOAD MASSES AT SINGLE ATTACHMENT POINT





FIRST GENERATION ERECTABLE JOINT BENDING STIFFNESS QUANTIFIED

Mark Lake
Structural Concepts Branch
Extension 2414 November 1986
RTOP 481-32-23 WBS 55-2
Code RM

Research Objective: To determine experimentally the static bending characteristics and equivalent bending stiffness of an erectable joint subassembly.

Approach: An aluminum joint subassembly consisting of a spherical node with two erectable joints was tested to determine its bending characteristics. Sections of aluminum tubing were attached to the two strut end fittings to allow effects of threaded interfaces between the struts and the fittings to be included. As a control specimen, a section of aluminum tubing without the joint was tested also.

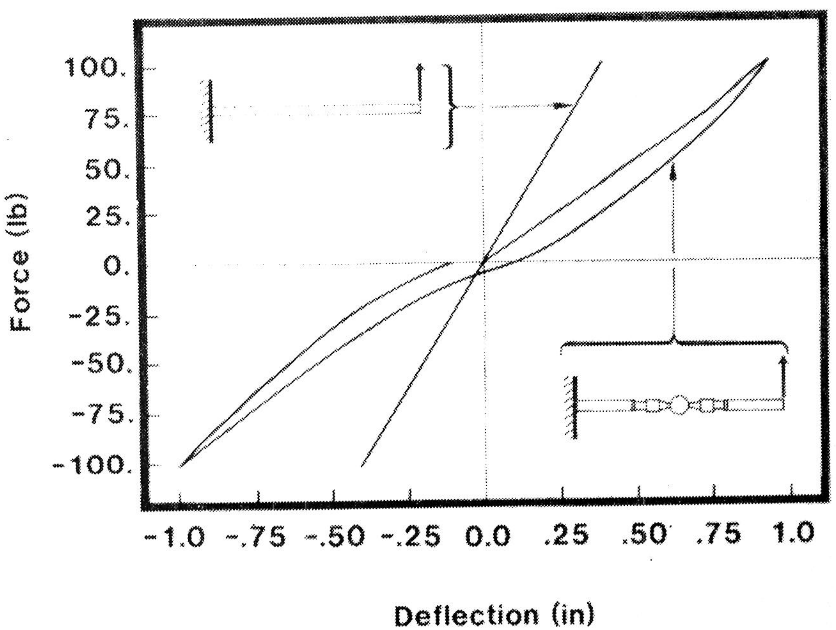
Accomplishment: In truss structures of the type being considered for Space Station, local vibration and buckling in the members and eccentric application of loads to joints give rise to bending loads in truss members. Therefore understanding of the bending characteristics of truss joints is mandatory for realistic design. As shown in the attached figure, the erectable joint considered herein was cantilevered at one end and statically loaded at the other end to produce bending deformations. The load-deflection curve in the accompanying plot shows non-linear stiffness behavior and a maximum hysteresis width of about 0.2 inch. It is believed that the threaded interfaces between the joint fittings and the struts are responsible for most of the hysteretic behavior shown. This behavior might be improved through revision of the thread design. Using a linear regression of the data, an equivalent bending stiffness (EI) for the joint section was calculated to be 0.86×10^6 (lb-in^2). This is approximately 25 percent of the bending stiffness of the aluminum tube used as a control specimen (2.0 in - O.D., 0.125 in thickness), and about 12 percent of the predicted bending stiffness of Space Station truss members.

Significance: Accurate prediction of local behavior in the Space Station truss structure depends on understanding of bending characteristics of truss joints. Further, in an effort to simplify analysis, performing tests on early generation hardware can aid in the evolution of a joint design which behaves linearly.

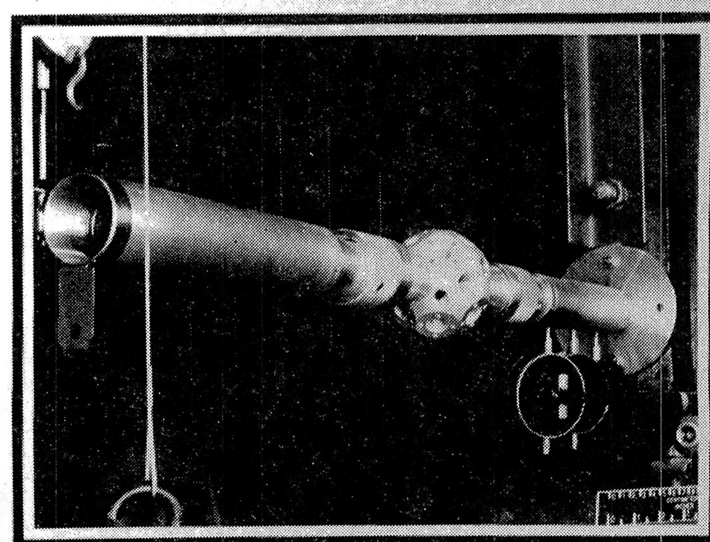
Future Plans: Similar tests will be conducted on improved hardware to aid in design evolution. Additionally, analysis of local structural performance with joint effects included will be performed.

FIRST GENERATION ERECTABLE JOINT BENDING STIFFNESS QUANTIFIED

TEST RESULTS



TEST SET-UP



TECHNICAL HIGHLIGHT

VIBRATION CONTROL METHOD INVESTIGATED FOR SPACE STATION

Harold G. Bush
Structural Concepts Branch
RTOP 506-43-41
Ext. 2498 February 1987
Code RM WBS 55-2

John R. Sesak
Lockheed Missiles and Space Co.
Sunnyvale, CA 94089
408-743-0132

Research Objective: Investigate the applicability of passive damping devices for structures characterized by highly distributed low strain energy such as Space Station.

Approach: Use passive vibration absorbers to draw energy to the damper. Apply and extend classical absorber design and optimization techniques to multi-mode/multi-degree of freedom systems. Apply modern control theory and parametric optimization techniques to generate optimal damper tuning laws.

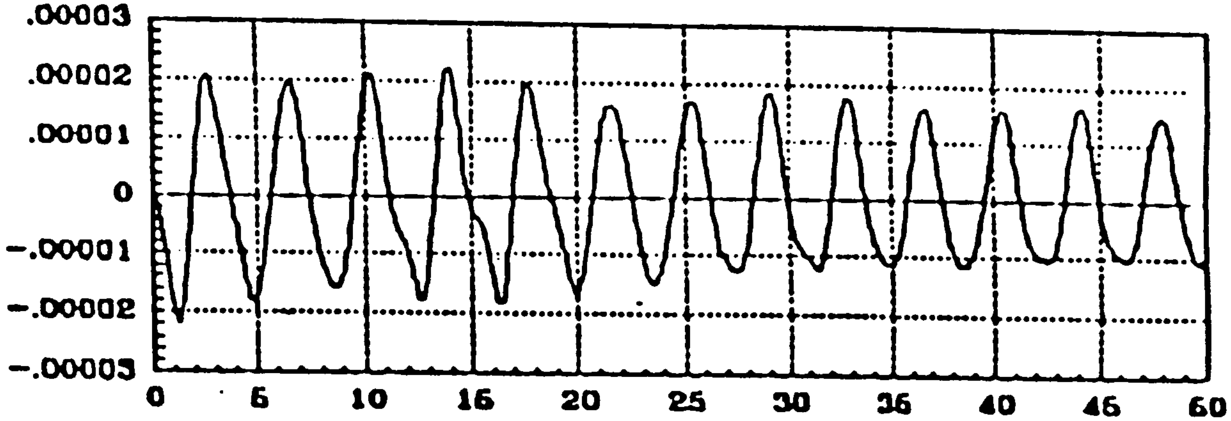
Accomplishment Description: A new tuning method for vibration absorbers has been developed. The design process for the general optimization problem is formulated as a linear output feedback control problem via the development of a feedback control canonical form. The design variables are expressed as control gains, and the analytical techniques of feedback control theory, both classical and modern, are applied to absorber design. A nonlinear parameter optimization method is developed and applied to an output feedback formulation of the vibration damping problem. Classical dynamic models are extended to investigate the effects of absorber placement, existing structural damping, and absorber cross-coupling on the optimal design synthesis. An uncoupled dynamic optimization technique is developed which allocates the absorber mass budget over multiple absorbers in order to optimally damp the transient response.

Significance: The tuned vibration absorber shows promise for Space Station vibration control. The devices were applied to the micro-g and pointing problems on the NASA dual keel Space Station. The optimally damped transient pitching response of the earth pointed boom (i.e., pointing problem) is compared to the open loop response in the attached figure. The combined total mass of these devices was limited to two percent (2316 lbm) of the primary modal mass of the station. Modal damping levels in the range of 10-20 percent were achieved with two tuned-mass dampers. One damper (2281 lbm) was located on the transverse section of the lower boom, and the other damper (35 lbm) was located at the tip of the outermost solar array. The potential damping performance improvement obtained through the use of tuned-mass dampers on lightly-damped structures (see figure) merits consideration of their use on Space Station. For Space Station applications, the dynamics and the low strain energy involved dictate a low frequency, low stroke, space-qualified design. A possible choice would be a magnetic device with no moving parts.

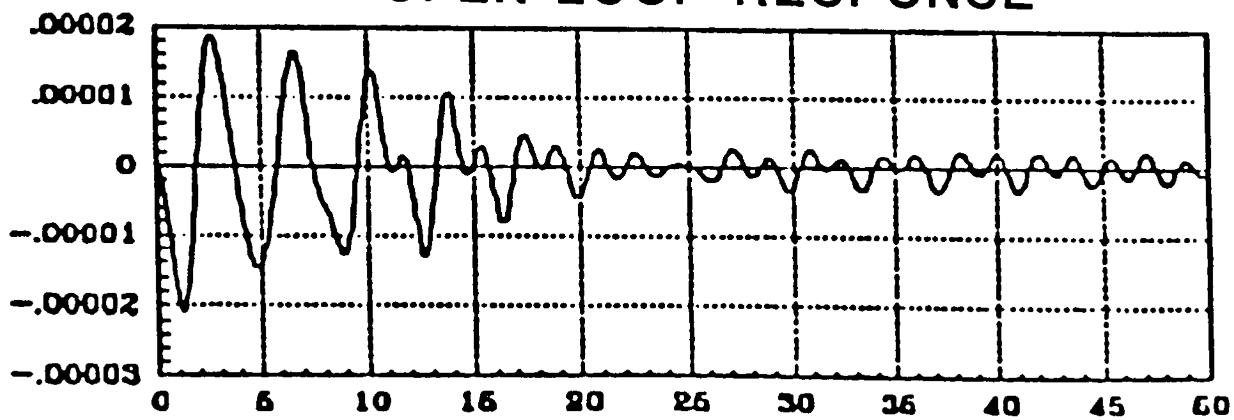
Future Plans: Conduct preliminary hardware design of absorber concepts. Construct and test hardware concepts.

EARTH POINTING BOOM TRANSIENT PITCHING RESPONSE

SPACE STATION



OPEN LOOP RESPONSE



RESPONSE WITH UNCOUPLED OPTIMIZATION

Lockheed

TECHNICAL HIGHLIGHT

WEIGHT EFFICIENT IN-LINE BOLTED JOINT FOR SPACE SHUTTLE SOLID ROCKET MOTOR CASE SEGMENTS SUCCESSFULLY DEMONSTRATED

John T. Dorsey, Peter A. Stein, and Harold G. Bush
Structural Concepts Branch
Ext. 2892, 2414, and 2498 March 1987
RTOP 506-43-41
Code RM WBS 55-2

<u>Research Objective</u>: The purpose of the research is to investigate the feasibility of an in-line bolted joint which can be used to join case segments of the Space Shuttle Solid Rocket Motor (SRM). The primary objective is to determine if a joint can be designed which remains closed in the vicinity of the O-rings during SRM firing such that the O-rings are never required to track moving surfaces. Efforts are also made to improve on an initial joint design which had excessive weight.

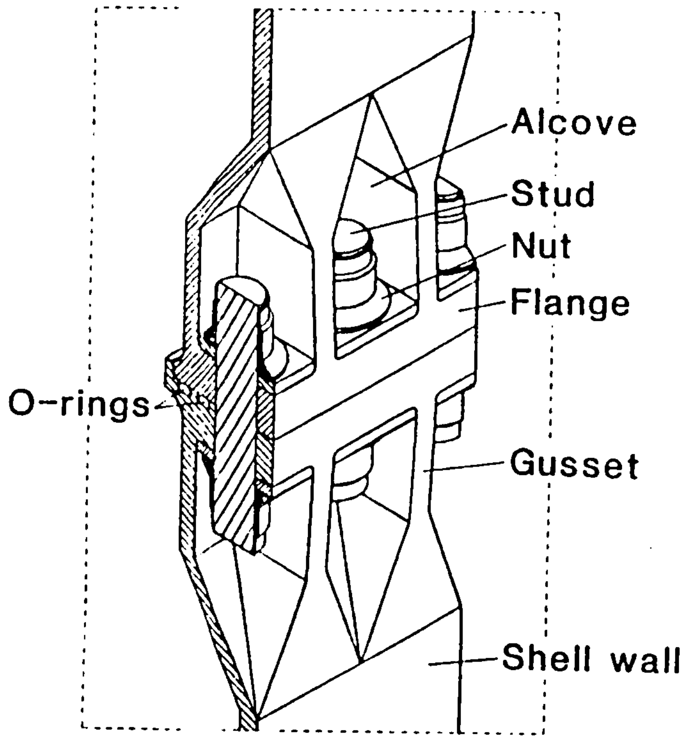
<u>Approach</u>: Finite element models of the joint are constructed using three-dimensional solid elements. The contact problem between mating case joint flanges is investigated using nonlinear contact elements. Parametric studies are performed to assess the changes in joint structural performance resulting from changes in design variables.

<u>Accomplishment Description</u>: A design for the in-line bolted joint concept has been developed (shown on the left side of the figure) which meets the primary objective of keeping the joint closed at the O-rings, while maintaining acceptable stress levels and minimizing weight. Parametric studies indicate that, in general, minimum weight is obtained by using; 1) the smallest stud size practical (as shown on the right side of the figure), 2) the smallest offset between the stud centerline and shell wall centerline, and 3) the smallest values of flange and gusset thickness practical. The 180-1" stud design shown in the chart has a weight penalty which is only 346 lbf (per joint) greater than the proposed capture tang fix.

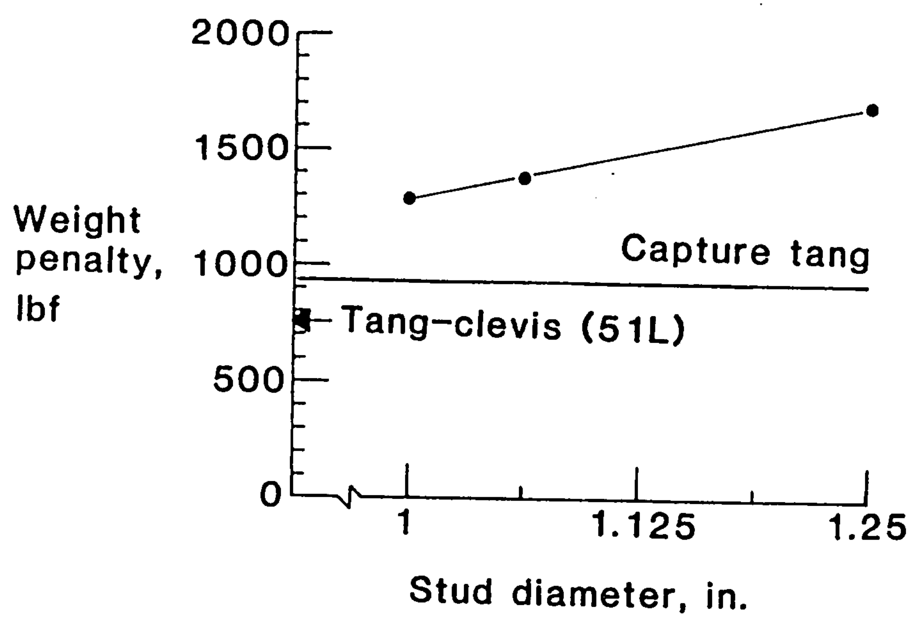
<u>Significance</u>: A weight efficient in-line bolted joint for the space shuttle Solid Rocket Motor (SRM) case segments is successfully designed to have no gaps at the O-ring locations during the entire SRM firing.

<u>Future Plans</u>: Material will be more efficiently tailored at the top of the alcove to reduce hoop stiffness in that area and allow the height of the alcove to be reduced. Both refinements in the design are anticipated to improve performance and reduce weight.

WEIGHT EFFICIENT IN-LINE BOLTED JOINT FOR SPACE SHUTTLE SOLID ROCKET MOTOR CASE SEGMENTS SUCCESSFULLY DEMONSTRATED



Analytical model geometry



TECHNICAL HIGHLIGHT

STRUCTURAL CONCEPT FOR A SPACE-BASED SOLAR CONCENTRATOR

W. B. Fichter
Structural Concepts Branch
Ext. 3596 June 1987
506-43-41
Code RM WBS 55-2

<u>Research Objective</u>: Projections of Space Station electrical power requirements have emphasize the need for high-efficiency, high-output generation capability. This research seeks to asses the feasibility of meeting a significant portion of the Space Station's power needs with solar reflector/concentrators.

<u>Approach</u>: Through a contract with Astro Aerospace Corporation, with John M. Hedgepeth as Principal Investigator, existing concepts for high-efficiency reflector surfaces were examined with emphasis on surface accuracies required to yield concentration ratios of 1,000 to 3,000. Also studied were the costs associated with achieving high collector efficiency, e.g., fabrication, ground testing, and surface adjustment.

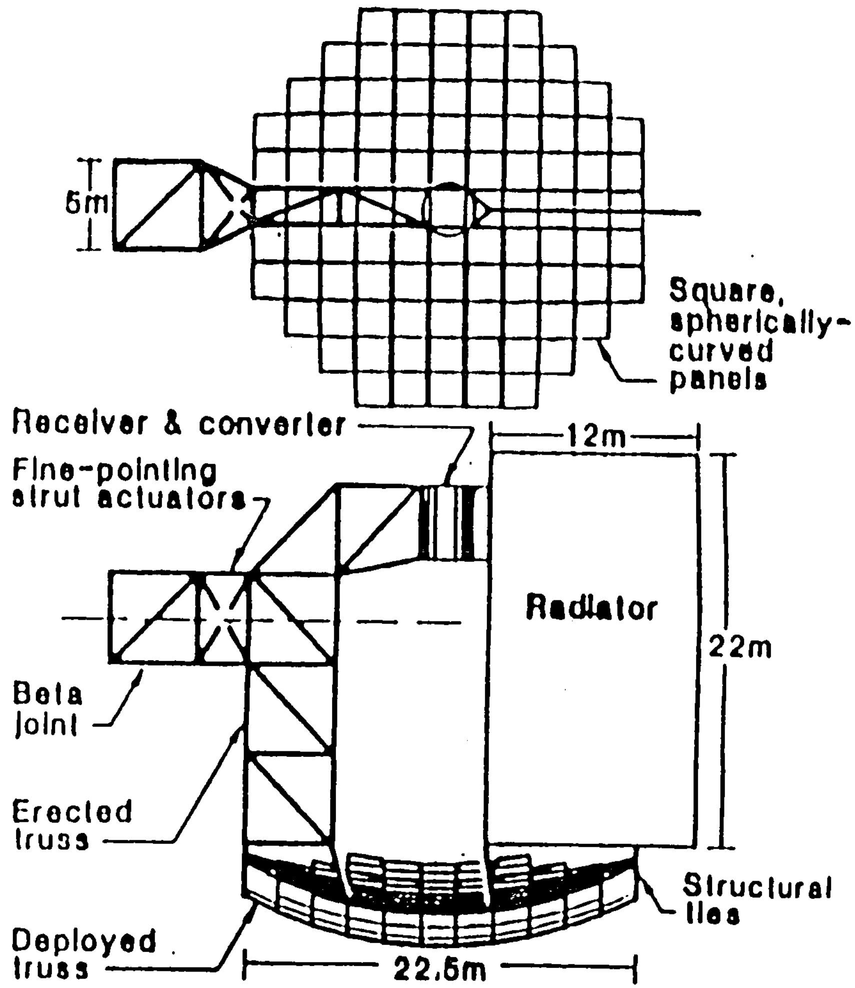
<u>Accomplishment Description</u>: A new configuration which addresses these cost issues is shown schematically in the figure. It consists of a deployable Pactruss backup structure on which identical, stiff, spherically curved reflector panels are mounted after deployment in space. The use of identical panels lowers fabrication costs, and the accuracy losses associated with the non-paraboloidal panel shapes are mitigated by optimal orientation of all panels. Analytical results suggest that, with reasonable pointing errors, the concept is capable of concentration ratios exceeding 2,000.

<u>Significance</u>: The concept's high efficiency and high vibration frequencies make it worthy of further study as an attractive power generation option for the Space Station.

<u>Future Plans</u>: Currently under consideration is a more detailed study of the relationship between cost and required concentrator precision. An important feature of such a study would be a comparison between the truss-supported and self-supporting panel concepts.

PACTRUSS-SUPPORTED SOLAR CONCENTRATOR CONCEPT

TOTAL MASS (COLLECTOR + MOUNTING STRUCTURE)	1339 kg
AREAL MASS DENSITY (TOTAL MASS/FRONTAL AREA)	4.1 kg/m^2
STOWAGE VOLUME (PANELS + TRUSS + CONNECTING TRUSS)	17 m^3
FREE-FREE FREQUENCIES (est.)	>10 Hz



STRUCTURAL DYNAMICS BRANCH

NEW FREQUENCY-DOMAIN EIGENSYSTEM REALIZATION ALGORITHM (ERA-FD) IMPROVES MODAL PARAMETER IDENTIFICATION

Jer-Nan Juang and Hideto Suzuki
Structural Dynamics Branch
Ext. 2881 November 1986
RTOP 506-43-51
Code RM WBS 42-1

Research Objective

The objective is to provide proof of concept for an identification technique in the frequency domain for large flexible structures, and to expose the close conceptual connection between time domain and frequency domain approaches to identification of modal parameters for linear dynamic systems.

Approach

A frequency domain eigensystem realization algorithm, via transfer functions, is developed using a known procedure formulated for the time domain Eigensystem Realization Algorithm (ERA), via free decay measurement data. Since the formulations of these two methods are closely related, the frequency domain technique will be referred to as the Eigensystem Realization Algorithm in Frequency Domain (ERA-FD). Transfer functions are the basic elements for the ERA-FD, which form a complex block matrix. Through the use of the complex block matrix and the singular value decomposition, a linear model is realized for a dynamic system matching the transfer function. The realized model is then transformed into modal space for modal parameter identification. As part of ERA-FD, accuracy indicators, namely, output modal amplitude coherence and modal spectrum coherence are developed. Important features in the frequency domain analysis include overlap averaging and windowing. The overlap averaging is used to smooth the transfer function for the complex block matrix, while the windowing is used to concentrate the analysis on the frequency range of interest. For illustration of the algorithm, examples are shown using simulated data and experimental data from a truss structure.

Accomplishment Description

The test article, shown in the figure, is a 26.25 ft by 3.75 ft flexible truss structure. The structure is suspended from the top using several long cables attached to the top member elements. Results are shown from a preliminary dynamic test of the truss structure conducted by exciting the structure with random signals. Frequency response functions were measured using eight accelerometers distributed over the test article. Three-dimensional spectra of these measurements are shown in the lower part of the figure. Each spectral peak represents one or more modes of the structure. The difference of the amplitude of each peak corresponding the sensor location shows approximately the mode shape. After being averaged according to the procedure developed, peaks are detected and a window is set for each peak. In this case eleven windows are set. The identified modes are thought to be good estimates of the real modes because they are in close agreement with spectral peak and have very high accuracy indicators.

Significance

The ERA-FD requires much less computation and storage than time domain techniques. The method is very promising for use in orbit measurements with a small flight computer.

Future plans

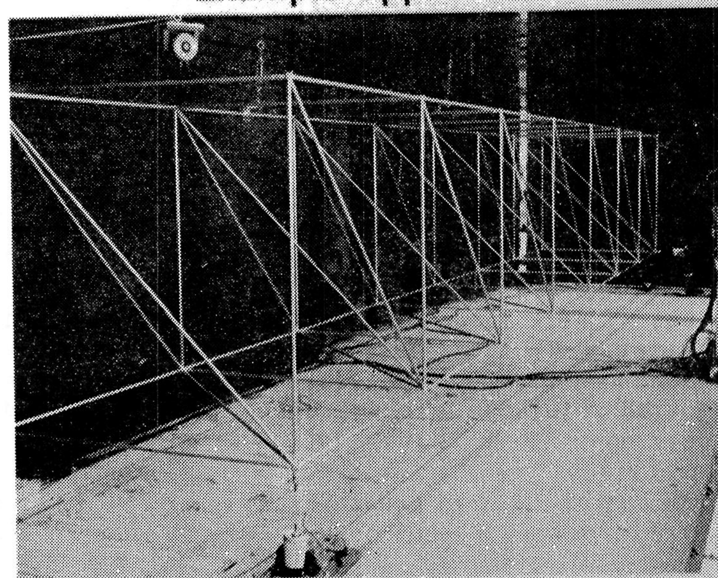
Further development is required to improve the practicality of the method. The computer program will be documented for public use.

NEW FREQUENCY-DOMAIN EIGENSYSTEM REALIZATION ALGORITHM (ERA-FD) IMPROVES MODAL PARAMETER IDENTIFICATION

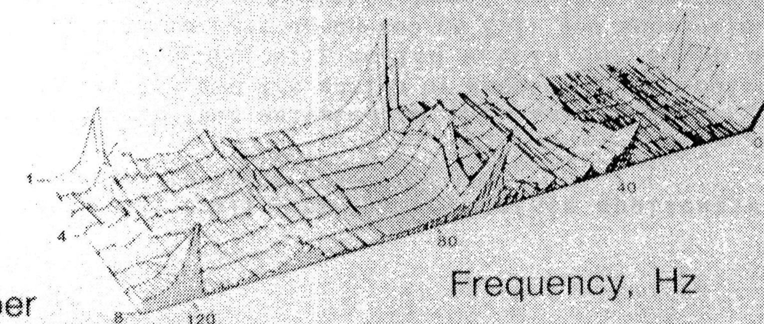
Improvements

- Direct solution without curve fitting
- Applicable with high damping
- Multi-input and multi-output capability
- Narrow-band analysis
- Lower computation and storage requirements
- Works with forced systems (not free-decay)

Example application



7 bay truss structure



Frequency response

FEASIBILITY OF SCALING STRUCTURAL JOINTS FOR AN ERECTABLE SPACE STATION

Paul E. McGowan
Structural Dynamics Branch
Extension 3615 January 1987
RTOP 482-53-53 WBS 42-1
Code RM

Research Objective: To examine the feasibility of geometrically scaling structural joints applicable to an erectable Space Station and predicting their behavior according to replica scaling laws.

Approach: An interim joint design for an erectable Space Station was selected as the basis for the scaling studies. Joint specimen were fabricated under contract at 1/3 and 1/4 scales by geometrically scaling from the full scale joint. Certain full scale features could not be practically scaled within the scope of this study (i.e., machining tolerances, screw threads). Static tests were conducted on full and sub-scale joints at appropriately scaled test conditions. Joint axial stiffness was calculated based on the measured load-deflection test data.

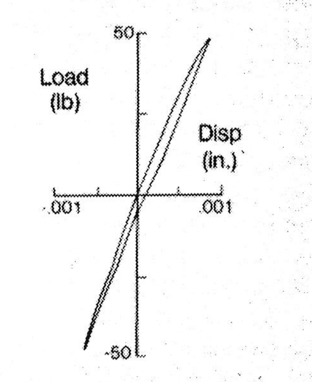
Accomplishment Description: Relatively good correlation between the results of the sub-scale and full-scale tests was achieved considering the quality of replication. Shown in the attached figure are the scaled axial stiffness values measured for the various joints as a percentage of the average full scale stiffness. The test data showed there is appreciable scatter in the measured axial stiffness among each size of joint (depicted as the shaded areas in the graph). This is probably due to variability in machining tolerances from joint to joint leading to misalignment of mating surfaces and variability in preload introduced when assembling the joint. It is realistic that a certain amount of scatter be present, yet, in practice, it can be reduced by more stringent quality control over the fabrication process. Theoretically if the sub-scale joints are completely replicated the axial stiffness should scale linearly with the scale factor. Thus, a one-fourth scale joint would have one-fourth the axial stiffness of the full scale joint. It was found that the average stiffness of the scaled joints appropriately multiplied by the theoretical scale factor were close to the predicted value based on replica scaling laws. The one-third and one-fourth scale joints were about 8% and 18% lower respectively than the predicted values. A major factor in the difference is attributed to the tolerances which were not scaled. The 1/3 scale joints could be machined with tolerances more like the full scale, thus they performed better.

Significance: A major challenge in conducting a successful test-analysis program on a scale model of Space Station is our ability to fabricate sub-scale joints which behave according to replica scaling laws. This initial attempt to scale joint stiffness is extremely encouraging and indicates that with improved manufacturing precision the stiffness of the full scale can be replicated down to 1/4 scale. These results also emphasize that scaling is more practical with larger scale models where the machining process can be better controlled.

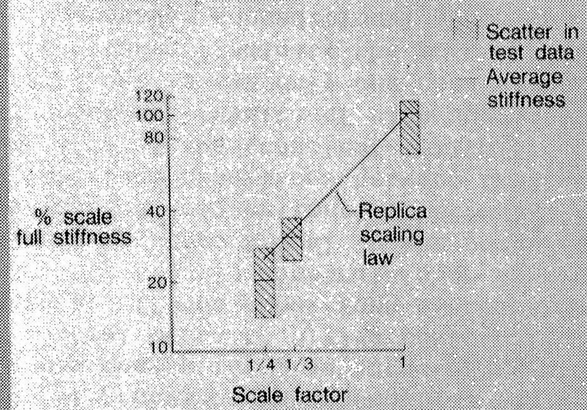
Future Plans: Replication of a more current erectable joint design with tighter control over the machining tolerances will be attempted. Comparisons of joint damping are being investigated and dynamic testing is planned for more accurate correlations. Analytical models which describe the nonlinear joint behavior are being developed.

FEASIBILITY OF SCALING SPACE STATION INTERIM ERECTABLE JOINT

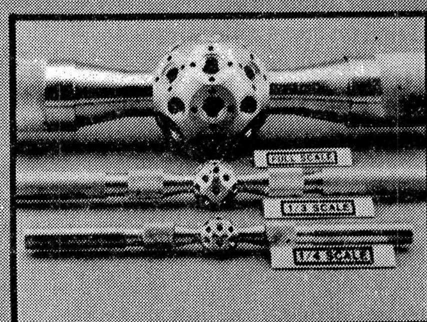
Typical joint static test data



Variation in measured joint axial stiffness



Examples of joint specimen



TRANSIENT RESPONSE ALGORITHM FOR NONLINEAR STRUCTURES MAGNIFIES SPEED GAIN ON PARALLEL COMPUTERS

Jerrold M. Housner

Structural Dynamics Branch
3055 April 1987
RTOP 506-43-51
Code RM WBS 42-1

RESEARCH OBJECTIVE: Develop new computational algorithms to achieve full potential of parallel supercomputers in predicting nonlinear transient structural response.

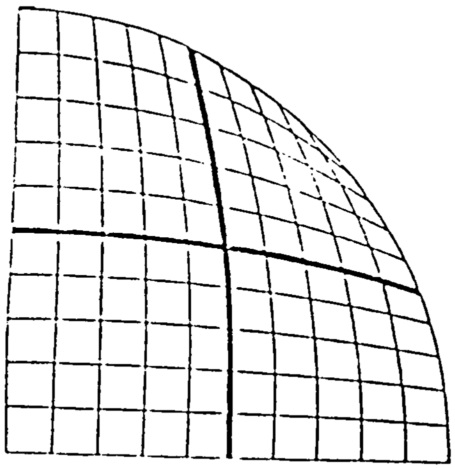
APPROACH: Multi-processor supercomputers offer a great potential for speeding up numerical analyses of complex structural dynamics and control systems. This potential can be tapped either by parallel computations using existing methods or by developing new computational methods tailored for multi-processor supercomputers. In the former case, the best performance possible is a one-to-one gain in computational speed; that is, N processors would perform the computations N times as fast. In the latter case, however, even greater gains in computational speed are attainable when the operations of the processors are nearly independent of one another.

ACCOMPLISHMENT DESCRIPTION: A new method for multi-processor supercomputers has been developed under grant to Brown University. The new method utilizes a non-conventional substructuring procedure for finite element transient analysis. Substructuring provides a natural means to divide computational tasks by allocating a processor to individual subdomains of the structure. If the conditions of compatability between the subdomains are satisfied in a conventional manner, (e.g., via constraints or Lagrangian multipliers), then the the potential gain in computational speed would be proportional to the number of processors used. This is shown in the accompanying chart by the curve labeled "conventional substructuring". However, in the new method an inertial rule is used to satisfy the interface conditions between the subdomains. This allows each processor to operate independently during a time step of the transient analysis. At the end of the time step, the inertial rule weights the independent processor results of each subdomain to achieve interface compatability. The inertial rule is not arbitrary, but is the only one consistent with the equations of motion. The two curves labeled "2-D" and "3-D Structures" indicate the potential gain in computational speed with the new method. In addition the new method possesses unconditional numerical stability; a valuable asset in structural dynamics algorithms.

SIGNIFICANCE: Multi-processor supercomputers offer potential for achieving the required efficiency for complex future aerospace structures. The transient algorithm discussed herein should prove a significant means of achieving that efficiency.

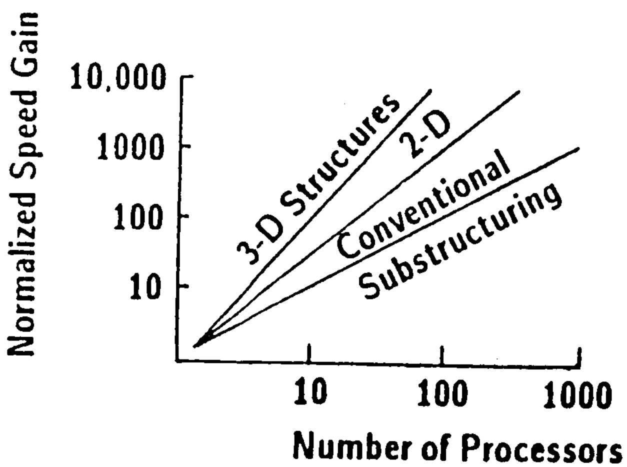
FUTURE PLANS: Incorporate the method into the testbed of the Computational Structural Mechanics (CSM) research program.

TRANSIENT RESPONSE ALGORITHM FOR NONLINEAR STRUCTURES MAGNIFIES SPEED GAIN ON PARALLEL COMPUTERS



Partitioned Structure

- NON-CONVENTIONAL SUBSTRUCTURING PERMITS DIVISION OF TIME INTEGRATION TO INDIVIDUAL PROCESSORS



Potential Speed Gain

- NEW INERTIAL RULE SATISFIES SUBSTRUCTURE INTERFACE CONDITIONS & CIRCUMVENTS TIME CONSUMING ASPECT OF CONVENTIONAL SUBSTRUCTURING

COFS-I ANALYSES SHOW ADEQUATE ACTUATOR PERFORMANCE FOR BASELINE DESIGN

Lucas G. Horta
Structural Dynamics Branch
Ext. 2738 July 1987
RTOP 542-06-11
Code RM WBS 42-1

OBJECTIVE: The Control of Flexible Structure (COFS) program depends on the proper performance of excitation/control actuators to fulfill the mission objectives. The baseline experiment requires excitation (to a measurable level) and damping of the 60-meter truss-beam. The objective of this work is to evaluate the contractor-designed system including a detailed representation of the actuators, actuator control electronics and truss beam dynamics.

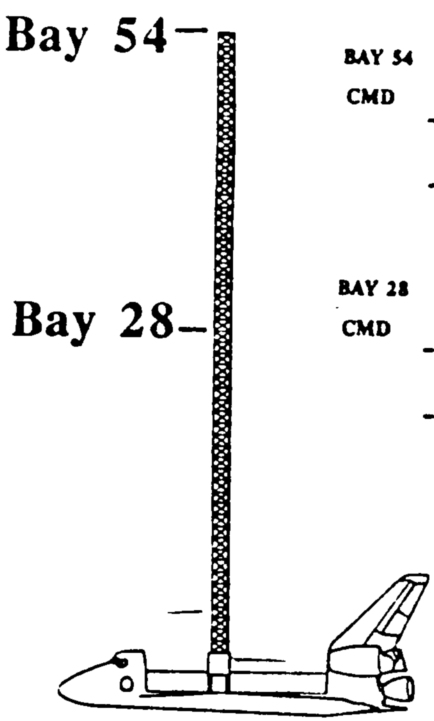
APPROACH: An interdisciplinary analysis was conducted using 16 modes from a detailed finite element model of the truss-beam. The actuators, which are basically lumped masses moving on linear tracks, were modeled using a fifth-order system. Position and acceleration sensors, on the moving masses are used to control proper input/output operation. Actuator models included current and input saturation limits, position sensor quantization effects and physical stops which limit stroke.

ACCOMPLISHMENTS: The design of the actuator controller has proven to be a major task. First, the actuators are stroke limited to 15 cm and 7 cm (tip and intermediate stations on the beam respectively). Second, they are force (current) limited to 30 N and 15 N. Third, their interaction with the beam when they are not in use must be kept to a minimum and, fourth, the actuator electronics must be implementable with analog components only. The physics of the actuators dictates that stroke limits the design at low frequencies whereas force is the limiting factor for high frequencies. A compromise was reached where these two factors were blended into a unified design. The figure shows simulation results for both excitation and damping of the first bending mode of the beam. Initially the actuators at the tip are commanded to produce a 10 cm sinusoidal motion for 55.5 sec and then switched to producing a damping force proportional to the velocity at the actuator location. The left hand plots show the commands to the actuators and those on the right show the resulting stroke for the tip actuator and the actuator at bay 28. The lower plot shows the tip response as a function of time. The actuators follow the commanded input very well until a saturation limit is encountered. When this occurs the input signal is clipped to an acceptable level. Observe that the tip actuator was prevented from contacting the 15 cm physical stop. The actuator displacement for bay 28 shows the effect of the $\pm$ 1 mm measurement quantization. This quantization also results in undesirable force spikes (not shown) which is an area needing improvement. The simulation shows the adequacy of the actuator controller to excite and damp the beam to satisfy the baseline requirements.

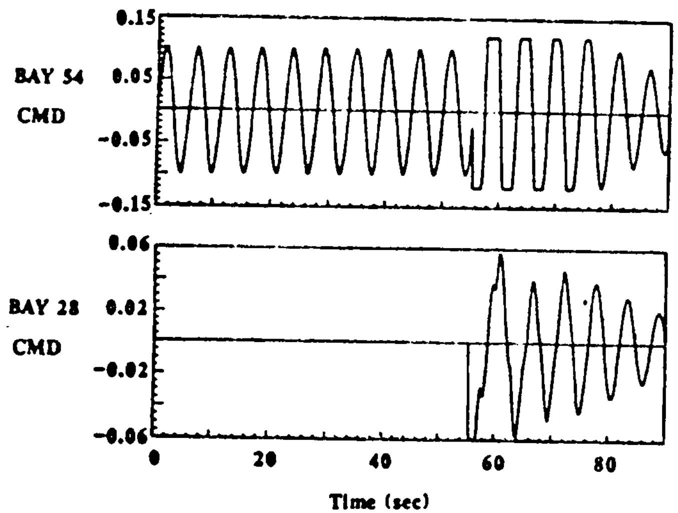
SIGNIFICANCE: Confidence in the ability to perform the COFS-I baseline experiments is improved.

FUTURE WORK: Perform parametric studies to optimize the design parameters. Assess excitation levels within the physical constraints of the system. Investigate the effects of time delay and model truncation errors on the system stability.

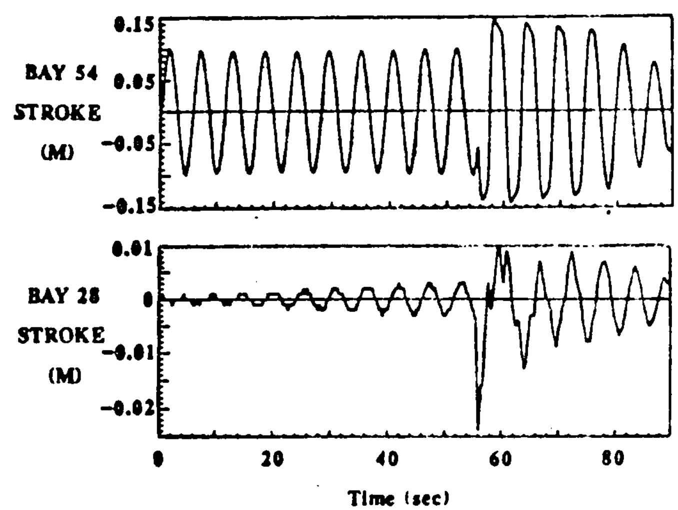
COFS-I ANALYSES SHOW ADEQUATE PERFORMANCE FOR BASELINE DESIGN



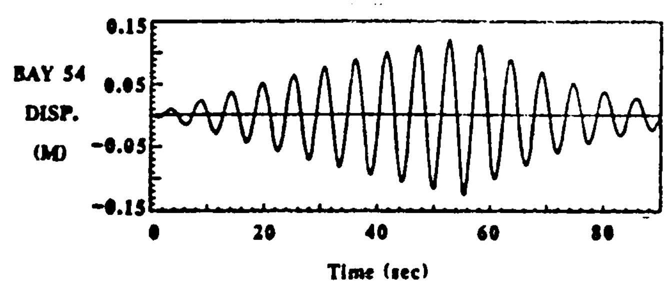
Actuator Command



Actuator Displacement



Beam Tip Displacement



INITIAL TEST RESULTS FOR THE MINI-MAST
(20-METERS TRUSS BEAM)

Lucas G. Horta and Garnett C. Horner

Structural Dynamics Branch
Ext. 2738/2817
Rtop 542-06-11 August 1987
Code RM WBS 42-1

OBJECTIVES: To learn how to test efficiently this type of large truss structure, to relate component testing (joints and tubes) to the overall behavior of the structure, and to update the associated analytical model based on experimental data, as necessary.

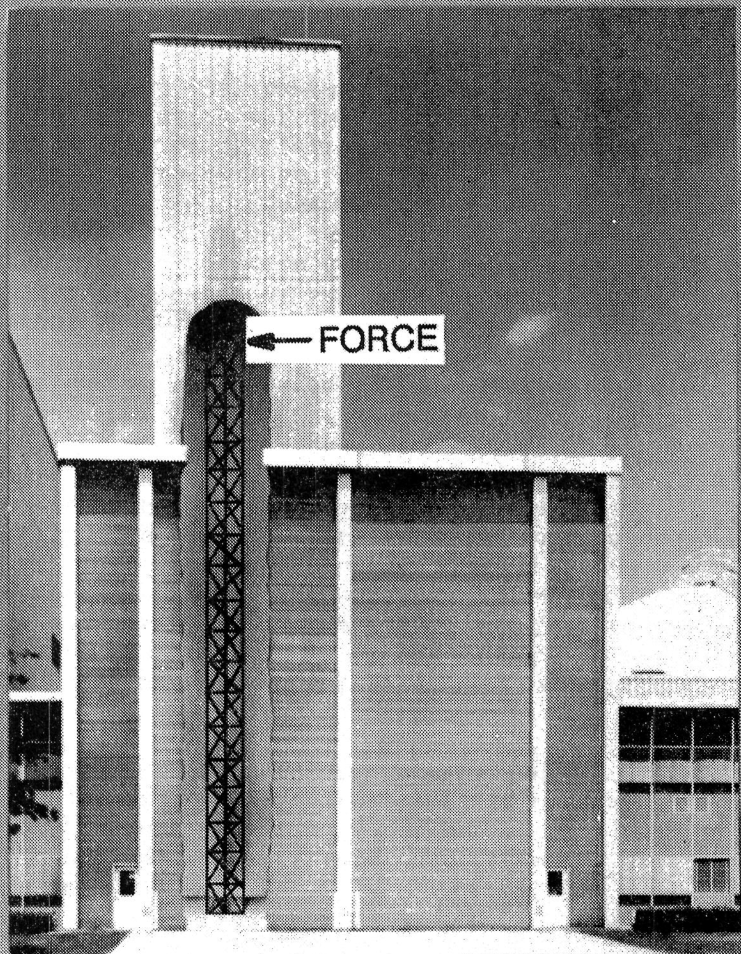
APPROACH: The Structural Dynamics Branch is conducting tests on a deployable, 20-meter truss-beam known as the Mini-Mast. The stowed structure is about 5 % of the fully-deployed 20 m length. A total of 111 titanium joints are used in deploying the 18-bay structure. To minimize the effect of instrumentation on the truss beam, non-contacting proximity probes are used to measure displacements. One probe is located at each vertex of the triangular cross sections to measure displacements. The sensed data is then transformed to a global coordinate system to recover the displacements at each bay. Bending and axial strain gages are used to monitor the member forces on the first two bays. The structure is supported on three load cells which measure the reaction forces at the base. The structure was statically loaded at the tip of the beam by a cable-pulley-weight arrangement. Impact testing was used for the initial dynamic test.

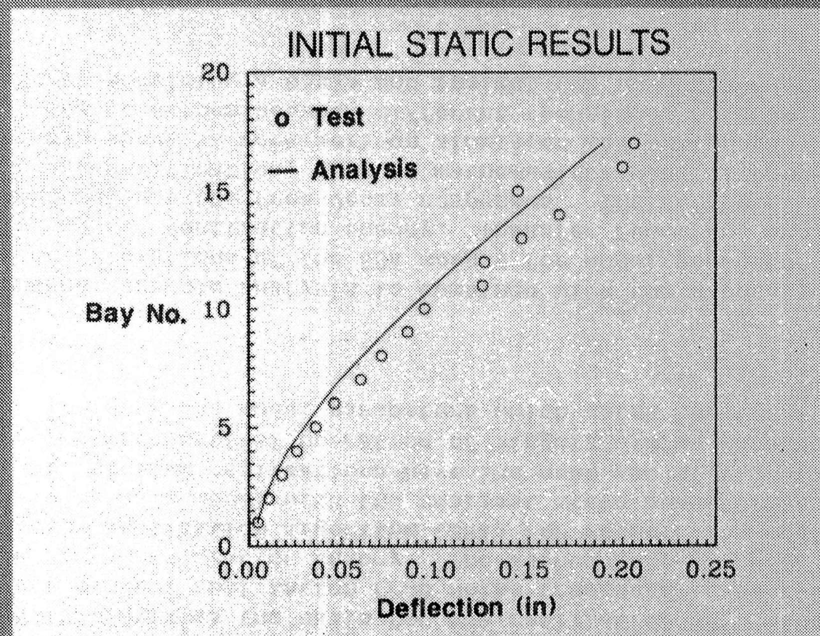
ACCOMPLISHMENTS: Initial testing of the beam includes verification of the measurement system which is, in itself, a major task. The data acquisition program reads 51 probes each time to recover the motion for 17 bays. The figure depicts a sketch of the truss beam overlayed on a picture of the Bldg. 1293B test tower to show its relative size. The beam is supported at the base and loaded at the tip with 5 lbs. The right hand plot shows the measured deflection (circles) of the CG and the solid line shows the predicted values from the finite element model as a function of the bay number. The analytical model appears to be stiffer than the measured response. To examine the fidelity of the finite element model a dynamic test was performed. The beam was impacted with a rubber hammer at a point seven bays above the base support and data from 15 probes was analyzed. Because of the low energy imparted to the beam, only the first three modes were identified. The identified modal frequencies and damping values are shown in the table along with the predicted values. Initial results show good agreement in the frequencies for the bending modes. The torsion mode is higher than the predicted value. The measure modal damping is below 1 %.

SIGNIFICANCE: The work shows the fidelity of the 20-meter deployable truss beam when compared to the existing analytical model and the capability of the existing measurement. In addition, this joint dominated structure exhibited low damping values, an indicator of high quality of the joints.

FUTURE PLANS: Examine several static loading conditions to verify and update the finite element model stiffness matrix. Incorporate component test data into the analytical model to improve prediction of the measured behavior. Conduct a detailed modal survey of the truss beam using multi-shaker excitation to update the analytical model using the mode shapes and frequencies.

INITIAL TEST RESULTS FOR THE MINI-MAST (20-METER TRUSS BEAM)





INITIAL DYNAMIC RESULTS

	ANALYSIS		TEST	
	FREQ. (HZ)	DAMPING (%)	FREQ. (HZ)	DAMPING (%)
1ST BENDING	1.44	*	1.45	0.6
1ST TORSION	7.11	*	8.54	0.4
2ND BENDING	9.66	*	9.47	0.5

NEW DEVELOPMENTS ADD VERSATILITY TO SYSTEM IDENTIFICATION BY EIGENSYSTEM REALIZATION ALGORITHM (ERA)

Jer-Nan Juang
Structural Dynamics Branch
Ext. 2881 August 1987
RTOP 506-43-51
Code RM WBS 42-1

Research Objective

The first objective of this research is to develop improved methods for analyzing measured dynamic data to estimate dynamic properties, i.e. modal parameters, such as damping, natural frequencies, mode shapes and modal participation factors. The second objective is to develop a unified mathematical framework to treat modal parameter identification so as to achieve an integrated understanding of the field of modal testing.

Approach

All the methods for modal parameter identification in the structures field start with either the frequency-based transfer function matrix or the time-based free-decay responses. The knowledge of either the transfer function matrix or free-decay responses makes it possible to construct a data matrix as the basis for the realization of a state space discrete-time model. The basic development of the state-space-model realization from noise-free data is attributed to Ho and Kalman who introduced the important principles of minimum realization theory. The methodology has been recently modified and substantially extended to develop the Eigensystem Realization Algorithm (ERA) for identifying modal parameters from noisy measurement data. Minimum realization means a model with the smallest state space dimension among possible systems having the same input-output relations. All minimum realizations have the same set of eigenvalues which are modal parameters of the system itself. Applying the mathematical operation of singular value decomposition to the data matrix, a state space representation is realized, yielding the modal parameters which match the transfer functions or the free-decay responses of the system.

Accomplishment Description

The solid theoretical and methodological foundations of modern controls analysis is combined with the extensive experimental knowledge from the modal testing field. Several variations of the ERA method for modal parameter identification, shown in the chart, have been derived using system realization theory. Transfer functions are the basic elements for the frequency-domain ERA, whereas the other methods use the free decay responses. The choice of methods can be made largely on the basis of the final purpose of the identification, such as mathematical model improvement or on-line control of flexible structures. All methods have been shown to work well on simulated and test data. There are a number of different important features for each method. The relations between different techniques have been explained and well correlated using system realization theory, providing a basis and insight for comparison and evaluation.

Significance

Through combing technology from the fields of control and structural dynamics, the diverse field of modal parameter identification is moving towards more unification. A common basis, via system realization theory, is found to explain and to select from the myraid of possible techniques.

Future plans

The computer programs for all ERA methods will be documented for public use. Further comparison and evaluation of the ERA methods with other existing methods will be made.

NEW DEVELOPMENTS ADD VERSATILITY TO SYSTEM IDENTIFICATION BY EIGENSYSTEM REALIZATION ALGORITHM (ERA)

Application* / Algorithm	Free Decay	Forced Response	Small Computer	On-line	Rapid Analysis	High Accuracy
Original ERA	X				X	X
Frequency domain ERA		X	X			X
Recursive ERA	X			X	X	
Data correlation ERA	X		X			X

*Assumes noisy data

ANALYSIS OF BEAM VIBRATION CONTROL USING EXTENSIBLE TRUSS LINKS

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Structural Dynamics Branch
RTOP 506-43-51
Ext. 2817
Code RM WBS 42-1

Harry H. Robertshaw
Virginia Polytechnic Institute
and State University
Blacksburg, VA 24060
703-961-7196

SEPTEMBER 1987

Research Objective

To evaluate the potential of active extensible links for vibration attenuation of truss-type structures.

Approach

A computer simulation of the control of a planar beam continuum attached to a truss composed of active extensible links has been conducted using physically realizable constants and concepts. The beam continuum was discretized using a three-mode Ritz expansion; the active-bay, consisting of ball screws driven by motors, was modeled as a collection lumped elements. The equations of motion are derived for large angle motion but were linearized for this initial study. Control laws were generated for this multi-input system using an LQR optimal approach.

Accomplishment Description

The simulations of this linearized model have shown the potential for excellent vibration control of the structure attached to the active bay. Calculation of the effective damping ratio for first-mode vibrations shows an increase of the damping ratio of this mode from an uncontrolled value of 0.014 to a controlled value of 0.62. The beam continuum has been modeled assuming no inherent damping; the uncontrolled value of 0.014 results from the open-loop interaction between the motors and the structure. It has also been found that there are optimal open-loop combinations of prime-mover (motor) characteristics and beam continuum characteristics. This effect has not been taken advantage of in this work. The control simulations show that the planar actuator motions are relatively small thus demonstrating the high authority that this actuator seems to have on the structure attached to it.

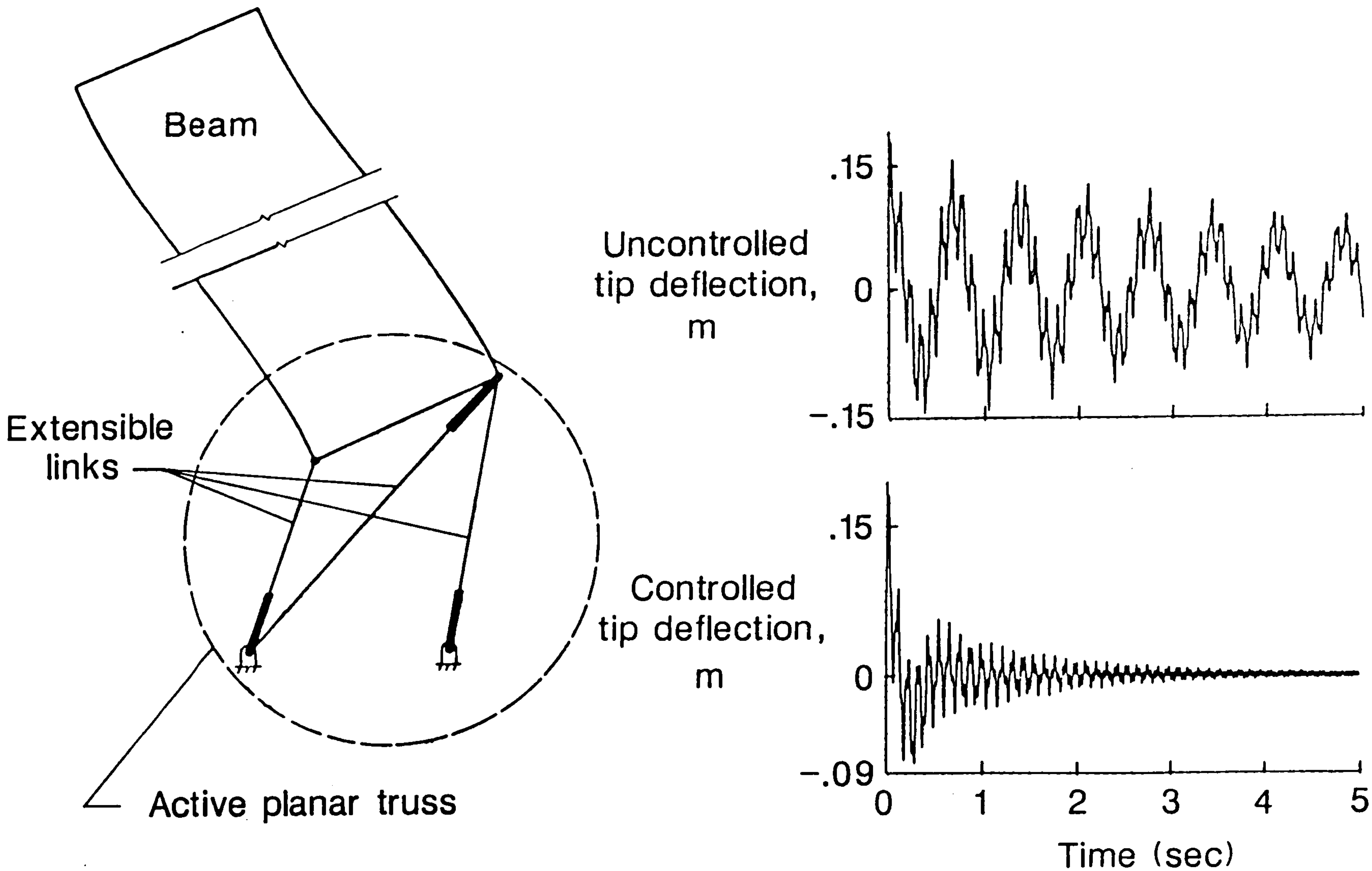
Significance

The concept of an active-bay actuator for controlling structural vibrations has been demonstrated through simulation. This concept of vibration has much promise in future applications.

Future Plans

This concept will be demonstrated experimentally in a planar test rig. Additionally, the analysis of a three-dimensional truss actuator will be carried out as well as experimental investigation of a different concept called the active geodesic truss.

ANALYSIS OF BEAM VIBRATION CONTROL USING EXTENSIBLE TRUSS LINKS



STRUCTURAL MECHANICS BRANCH

ASSESSMENT OF DAMAGE TOLERANCE AND RESIDUAL STRENGTH OF PRVT SPAR AND COVER-SKIN SPECIMENS

Osvaldo F. Lopez
Structural Mechanics Branch, SDD
Ext. 3179 October 1986
RTOP 534-06-23
Code RM WBS 56-1

Research Objective

To determine the effects of impact damage and long-term durability testing on the structural response of large graphite-epoxy aircraft structural spar and cover-skin components.

Approach

The Lockheed Corporation fabricated 22 cover-skin panels and 22 spars for the NASA/ACEE L-1011 vertical fin Production Readiness Verification Test (PRVT) program. Ten of each component were statically tested to failure to provide control or reference data. The remaining specimens were placed in environmental chambers and subjected to 10 and 20 years of simulated flight service conditions. Eighteen of the conditioned specimens were statically tested to failure at Langley Research Center. Eleven tests were conducted to determine the effects of simulated flight service on residual strength, and seven impact tests were conducted to assess the effects of damage on structural response.

Accomplishment Description

The attached chart illustrates the results of impact and residual strength tests. The upper photographs show a typical spar specimen constructed of T300/5208 graphite-epoxy tape and a typical failure mode. Failure was caused by local delaminations which initiated at the edge of the middle access hole and subsequently propagated to both edges of the specimen. Plotted on the right are the results of the impact and residual strength tests for the spar specimens. The first graph represents the failure loads of 10 control specimens. The remaining graphs show the failure loads of the conditioned and the impact-damaged specimens. The spar specimens were impacted either at the edge of the middle access hole or in the web between stiffeners. The results indicate that the conditioned specimens and the damaged specimens failed within the average failure load of the control specimens.

The lower photographs show a typical cover-skin panel constructed of T300/5208 graphite-epoxy tape and a typical failure mode. Failure occurred due to large postbuckling deformations which caused the center stiffener to separate from the skin and propagate the resulting damage across the specimen. Plotted on the right are the results of the impact and residual strength tests for the cover-skin specimens. The first graph represents the failure loads for ten control specimens. The remaining graphs show the failure loads for the conditioned and the impact-damaged specimens. The cover-panel specimens were impacted in the skin between stiffeners. The results indicate that the conditioned specimens and damaged specimens failed within the average failure load of the control specimens. When a cover-skin specimen was impacted at the stiffener flange, a 50 percent reduction in failure load occurred.

Significance

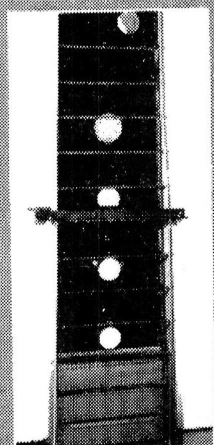
The results of the PRVT test program indicate no strength degradation due to simulated flight service conditions. Impact-damage test results show the spar components to be damage tolerant while the cover-skin panels showed strength degradation due to impact damage.

Future Plans

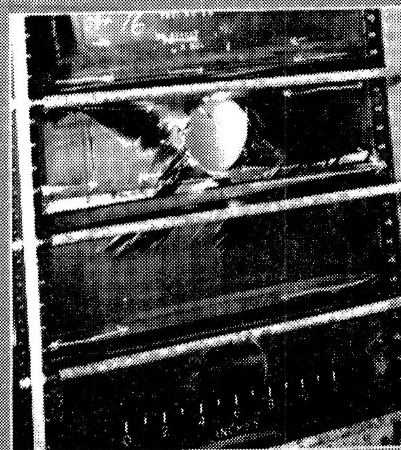
To conduct analytical studies of both spar and cover-skin panel specimens using a finite element procedure.

ASSESSMENT OF DAMAGE TOLERANCE AND RESIDUAL STRENGTH OF PRVT COVER AND SPAR SPECIMENS

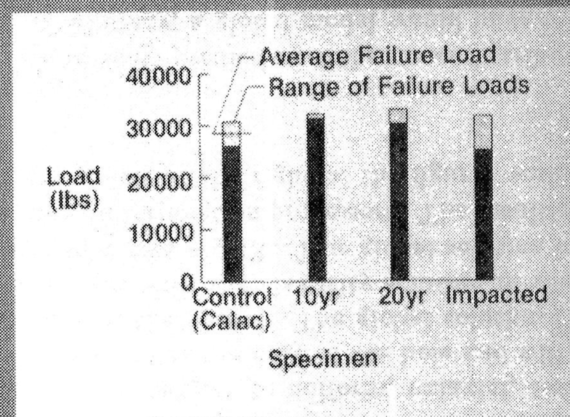
L-1011 Vertical Fin Spar



Failure Mode

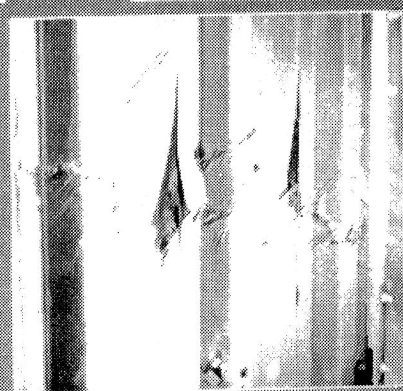


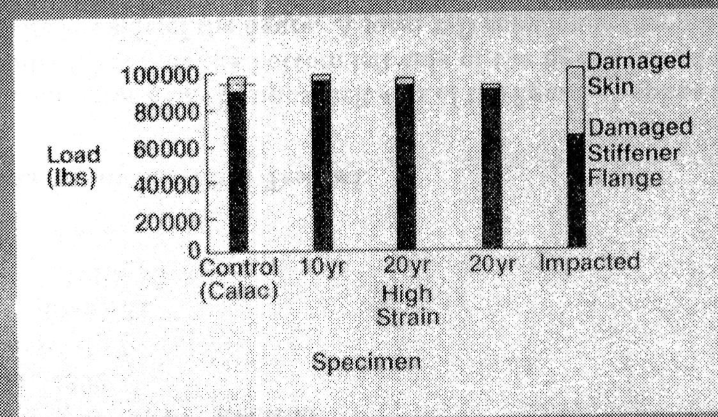
Residual Strength and Impact Test Results



L-1011 Cover-Skin Panel

Failure Mode





2-D GLOBAL/LOCAL ANALYSIS PERFORMED USING CSM TESTBED

Norman F. Knight Jr. and Susan L. McCleary
CSM Group, SMB PRC Kentron
Ext. 4892
January 1987
RTOP 505-63-31
Code RM WBS 56-3

Research Objective
To develop methodology for a 2-D global/local analysis capability within the CSM Testbed.

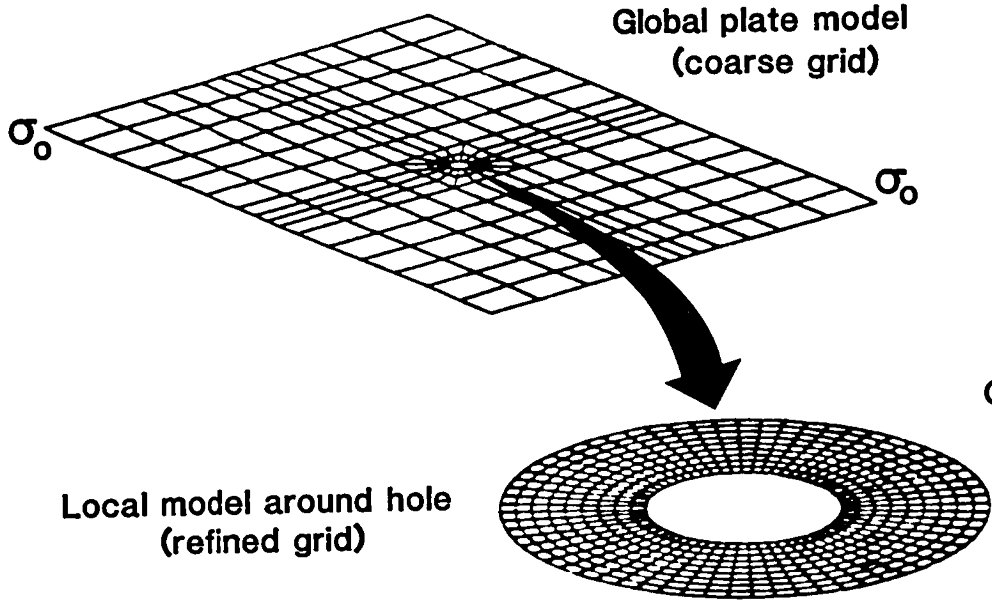
Approach
A complete finite element analysis is performed using the global model shown on the upper left side of the figure. A spline interpolation is used to impose displacements at the boundary of the local model (shown at the bottom left side of the figure) based on the static displacements of the region of the global model shown in the middle left side of the figure. A local 2-D solution is then obtained based on the imposed displacement boundary conditions from the global 2-D solution. Two computational processors have been installed in the CSM Testbed for a 2-D global/local capability. The first processor, SPLN, forms the spline coefficient matrix while the second processor, INTS, performs the point-by-point interpolation of the global solution to the boundary conditions of the local model.

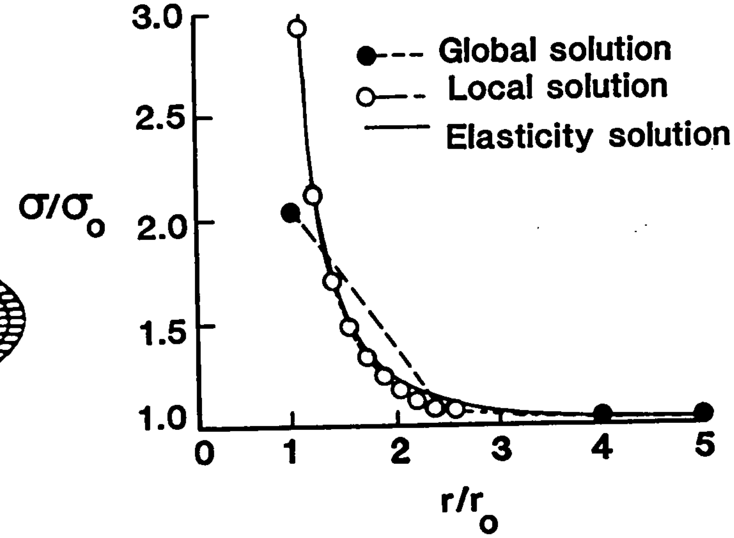
Accomplishment Description
For a large, thin, isotropic plate with a small central hole of radius r_0, subject to uniform, uniaxial, tensile stress, σ_0, elasticity theory shows that the stress concentration factor will have a value of three at the edge of the hole and will vary with distance from the hole as shown by the solid curve in the graph (at the right side of the figure). The global solution (represented by the solid circles in the graph at the right of the figure) provides good agreement with the elasticity solution in the far field but very poor agreement in the region near the hole; errors in the hole region are in excess of 32%. This global solution is used to define imposed displacement boundary conditions for the local model using the spline interpolation processors. The resulting local solution predicts stress concentration factors (represented by the open circles in the graph at the right of the figure) within 2.5% of the elasticity solution in the neighborhood of the hole.

Significance
This approach for a 2-D global/local analysis capability provides an accurate prediction of the stress distribution near a discontinuity using a local finite element model. To achieve this same degree of accuracy, a global model would have to be comparably refined, not just in the region of the hole, but also away from the hole. The solution of such a large global finite element model would be extremely expensive in terms of computer resources.

Future Plans
Testing of the 2-D global/local methods will be carried out on composite laminates and extensions for a 2-D/3-D transition will be made. The analysis will be made routine by developing criteria for selection of the "local region."

2-D GLOBAL/LOCAL ANALYSIS PERFORMED USING CSM TESTBED





- Global solution defines boundary conditions for local model
- Local model includes only region around hole
- Compared with single analysis having same accuracy, proposed multi-level approach:
  - Reduces modeling effort
  - Reduces computational costs

Structural Response of Redesigned SRM Joint Nearly Insensitive to Pressure Distribution

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CSM Group/SCB CSM Group/SMB
Ext. 4892
February 1987
RTOP 506-43-41
Code RM WBS 56-2

Research Objective

To understand the structural response of the SRM tang-clevis joint by determining its sensitivity to O-ring sealing assumptions characterized by various pressure distributions.

Approach

Detailed three-dimensional-solid finite element models of a one-degree slice of the original and redesigned joints were developed. Various pressure distributions were considered including that of a factory joint which is completely insulated.

Accomplishment Description

An understanding of the SRM tang-clevis joint sensitivity to O-ring sealing assumptions was developed by considering characteristic pressure distributions. Moving from left to right on the slide, the first case is representative of both the original and the redesigned SRM factory joint (joining performed at the factory) for which the internal insulation acts as the primary seal. For the field joints (joining performed at the launch center facility) using the original tang-clevis joint, the case where the primary O-ring does seal and the case where the primary O-ring fails to seal but the secondary O-ring does seal are considered, respectively. The next three cases are for the redesigned SRM joint with an interference fit capture feature. The first case assumes that the O-ring in the capture feature does seal. The next case assumes that the primary O-ring seals and the final case assumes that the secondary O-ring seals. The results for the original joint indicate that not only is the average gap motion large, it is also very sensitive to pressure distributions (i.e., performance of the O-rings). However, the redesigned SRM joint is shown to substantially reduce the average gap motion and to be nearly insensitive to pressure distributions.

Significance

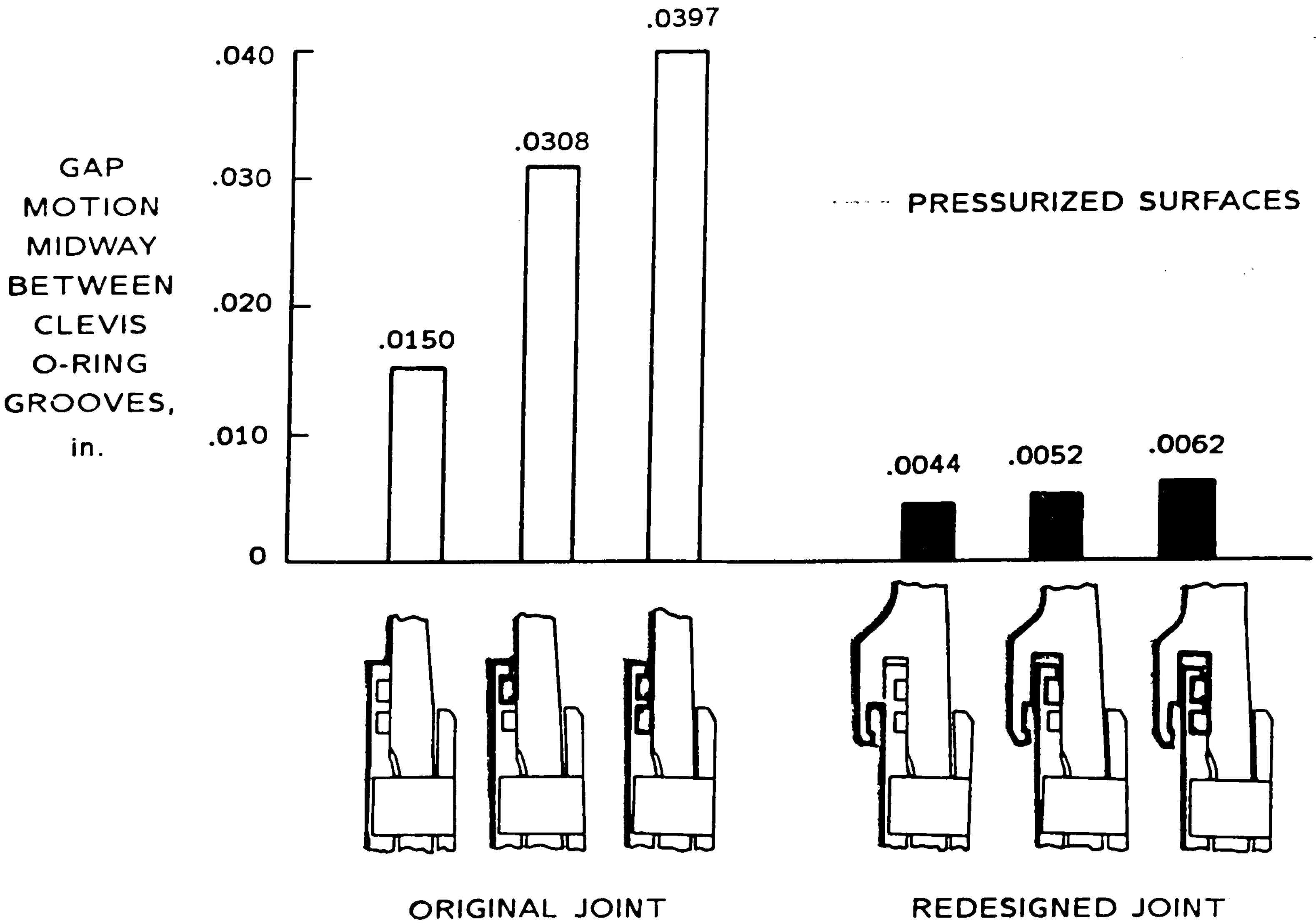
Inclusion of an interference fit capture feature on the SRM field joints will limit the relative motion that can occur between the inner clevis arm and the tang. The redesigned joint will also be nearly insensitive to pressure distributions.

Future Plans

The analytical models developed to date will be used in supporting the Marshall Space Flight Center SRM Redesign Team.

NASA
L-86-11,259

STRUCTURAL RESPONSE OF REDESIGNED SRM JOINT NEARLY INSENSITIVE TO PRESSURE DISTRIBUTION



CAPTURE TANG CLEARANCES GREATLY AFFECT O-RING GAP

Melvin S. Anderson and Michael P. Nemeth
Structural Mechanics Branch
Ext. 4052 April 1987
RTOP 505-63-11
Code RM WBS 56-1

Research Objective
To determine the effects of capture tang initial clearances on solid rocket booster (SRB) field joint deflections at the O-rings.

Approach
Structural deformations of the capture-tang and clevis SRB field joint were obtained by using an influence coefficient method to simulate contact between adjacent shell walls. The analysis included computing the structural displacements at various assumed contact points resulting from the applied pressure loading and unit loads applied at the assumed contact points to represent contact forces. The results were obtained using the axisymmetric shell-of-revolution analysis code FASOR along with an in-house computer program for determining the contact forces and resulting joint displacements.

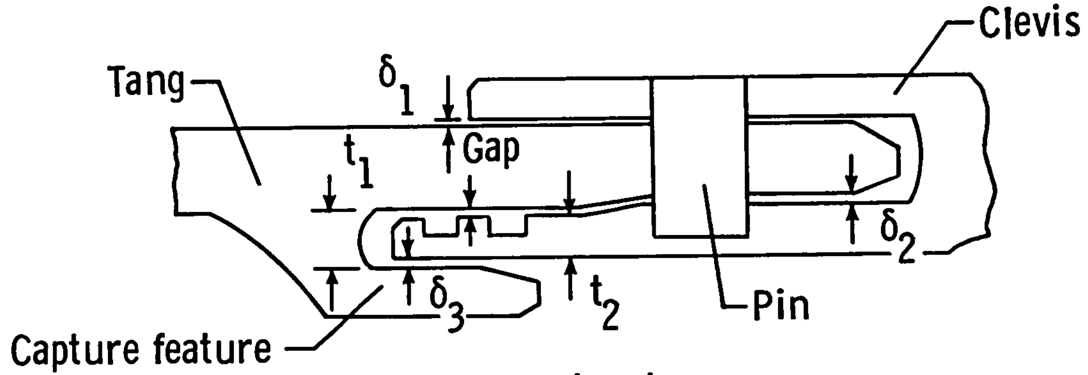
Accomplishment Description
The chart indicates the effect of initial clearances on the O-ring gap resulting from loads introduced by joint assembly (no internal pressure) and from the 1000 psi internal pressure loading that the SRB is subjected to during motor operation. The joint details are shown in the upper figure. The parameter μ is the clearance resulting from the difference in the thicknesses of the clevis inner lug and the channel that it slides into during assembly. Three other joint clearances δ_1, δ_2, and δ_3, are indicated in the upper figure. A capture-tang interference fit is obtained for negative values of δ_3. The initial O-ring gap is given by $\mu - \delta_3$.

The results presented in the lower left figure indicate how the absolute O-ring gap changes as a function of the joint clearances for the nominal case of $\mu = 0.02$ inches. The unpressurized assembly conditions are represented by the dashed curve and the 1000 psi pressurized conditions by the solid curves. The shaded region between the solid curves represent the influence of different values of δ_1 and δ_2. The results indicate that positive increases in μ_3 reduce the initial absolute O-ring gap prior to motor pressurization. Motor pressurization increases the gap by approximately 0.006 inches (the difference between the solid and dashed curves) for values of δ_3 less than 0. Somewhat larger increases in gap due to pressurization are shown for positive values of δ_3, but the resulting absolute gap decreases. The results shown in the lower right figure indictate that reducing μ tends to reduce substantially the absolute O-ring gap both before and after motor pressurization. The absolute gap decreases to less 0.005 inches with values of δ_3 greater than 0.

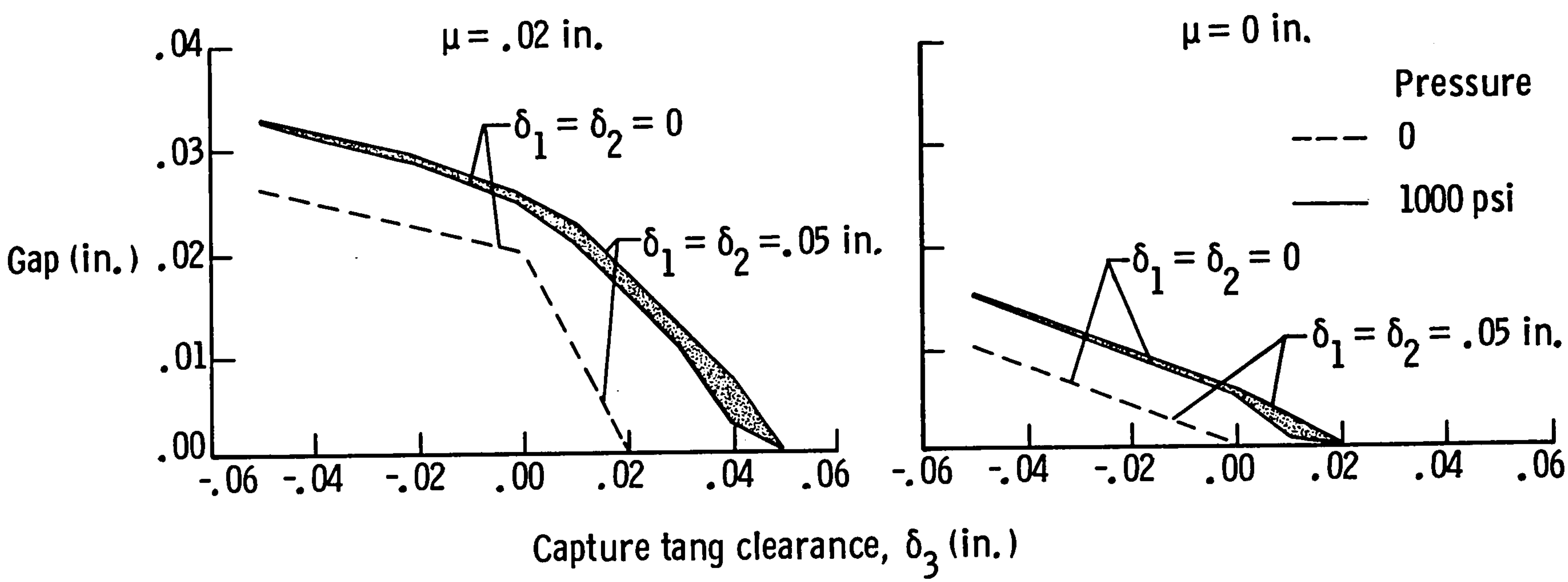
Significance
The results presented should be useful in assessing joint performance as a function of various O-ring sealing characteristics such as material composition, size and temperature. Once the characteristics are known for a given O-ring, the range of clearances at which the joint is functional can be directly determined.

Future Plans
To conduct similar parametric studies for the capture tang and clevis joint containing a third O-ring located on the capture tang.

CAPTURE TANG CLEARANCES GREATLY AFFECT O-RING GAP



$\mu = t_1 - t_2$



Third-Order Shear Deformation Theory Developed for Laminated Composite Plates and Shells

Norman F. Knight, Jr.
CSM Group/SMB Ext. 4892
RTOP 505-90-28 June 1987
Code RM WBS 99-01

Research Objective

To develop a simple, variationally-consistent, higher-order theory for laminated composite plates and shells that accounts for a parabolic distribution of the transverse shearing strains through the thickness of the laminate.

Approach

The approach developed by Professor J. N. Reddy at Virginia Tech under NASA Grant NAG-1-459 (March 16, 1984 to March 15, 1986) was to assume a displacement field that satisfies the conditions that the transverse shear stresses vanish on the laminate surfaces and be nonzero elsewhere. The inplane displacements were expanded as cubic functions of the thickness coordinate and the transverse displacement was assumed to be independent of the thickness coordinate. The equilibrium equations were derived using the principle of virtual displacements and then used to develop a two-dimensional plate/shell finite element.

Accomplishment Description

A higher-order (third-order) theory that accounts for the tranverse shear strains and the corresponding finite element models were developed. Analytical solutions based on the Navier method were also developed for certain cross-ply and angle-ply laminates with two different types of simply-supported boundary conditions which serve as reference solutions for comparison with the finite element results. A representative problem is shown on the right hand side of the slide. This problem is a simply-supported square orthotropic plate subjected to a uniform pressure loading. Finite element analysis results using the classical plate theory (no shear deformation) and the present theory are shown in the figure and compared with the experimental results. These results indicate that shear deformation had little effect on the linear solution. However, including shear deformations in the geometrically nonlinear analysis had a significant effect on the analytical predictions. The nonlinear analysis results using the present theory correlate well with the experimental results.

The research lead to more than a dozen publications in archival journals and proceedings at national and international conferences for Dr. Reddy and his students. Under this grant, Dr. Reddy directed one master's and two doctoral students.

Significance

Three major conclusions resulted from this grant. First, for thick laminates, shear deformation theories predict deflections, stresses, vibration frequencies, and buckling loads significantly different from those predicted by classical theories. Second, even for thin laminates, shear deformation effects are significant in dynamic and geometrically nonlinear analyses. Third, the present third-order theory is more accurate compared to the classical and first-order theories in predicting static and dynamic response of laminated composite plates and shells.

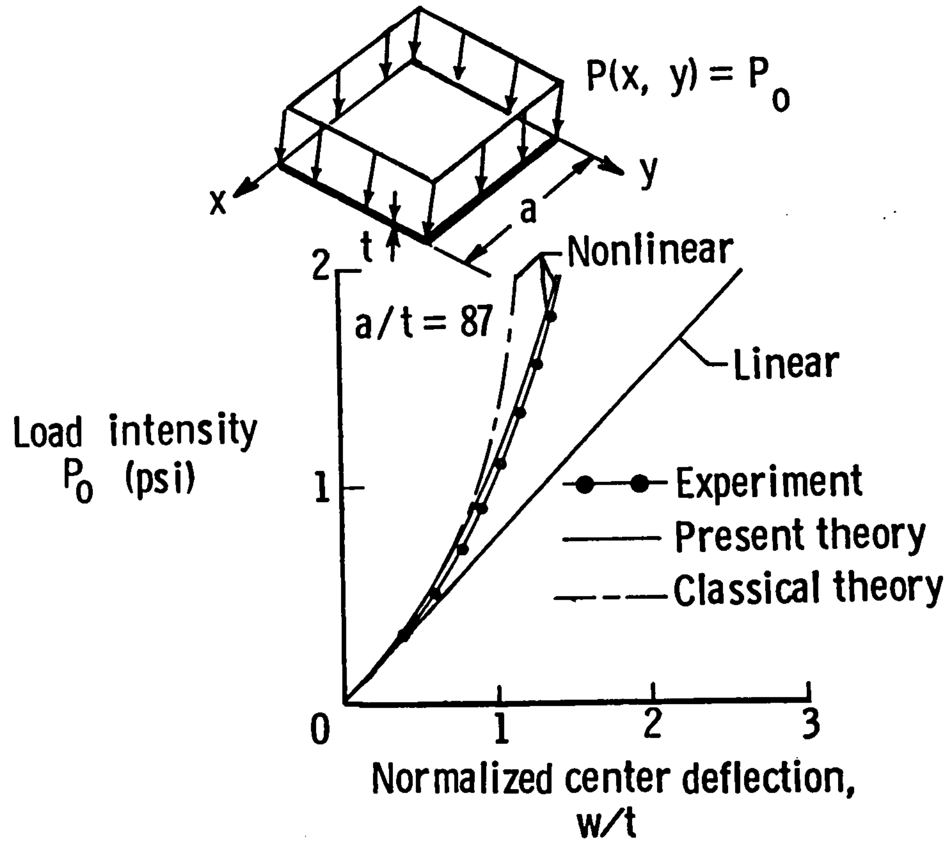
Future Plans

Document the grant activity in a low-number NASA Contractor's Report.

THIRD-ORDER SHEAR DEFORMATION THEORY DEVELOPED FOR LAMINATED COMPOSITE PLATES AND SHELLS

- Shear deformation effects are significant in nonlinear analysis even for thin laminates
- Variationally consistent theory
- Inplane displacements cubic in thickness direction
- Stress-free boundary conditions satisfied

Simply Supported Square Orthotropic Plate under Uniform Pressure Loading



STRUCTURAL ANALYSIS CODE STAGS OPERATIONAL ON NAS COMPUTER

Ronnie E. Gillian and Norman F. Knight, Jr.
CSM Group, SMB
Ext. 3195 Ext. 4892

RTOP 505-63-11 July 1987
Code RM WBS 56-2

Research Objective:
To implement STAGS 2-D shell finite element analysis computer code on the NAS computer (CRAY-2) and to perform nonlinear structural analyses of the Space Shuttle solid rocket boosters (SRB).

Approach:
The STAGS computer code has been under development with Lockheed Palo Alto Research Laboratory for over ten years. The development was initiated to support the design and analysis of the Space Shuttle system. The approach was to convert the existing program to run under the UNICOS operating system and to provide access to the NAS from local computers at Langley.

Accomplishment Description:
Approximately 90,000 lines of Fortran code were converted to run under the CFT77 Fortran compiler, and the low level I/O routines previously written in assembly language were replaced by C language routines. Operational aspects of the remote access to NAS are described on the figure. The Langley CSM VAX, shown in the upper left, is used for model preparation and verification. The STAGS input datasets are then transmitted via NASNET to the NAS computers, shown in upper right, for execution. The STAGS output files and restart files are returned via NASNET to the CSM VAX for postprocessing and are subsequently transmitted via LARCNET to the Langley central computer system for printing, microfiche, plotting, and archival storage. For example, a nonlinear analysis of the SRB at a load condition known as max twang (deformed geometry shown in figure) has been performed on the NAS CRAY-2 computer. The STAGS finite element model of the SRB involved nearly 83,000 degrees-of-freedom and required 60 million 64-bit words of main memory and 800 megabytes of temporary disk space. The linear stress analysis of this model required 853 CPU seconds and the nonlinear stress analysis required 3824 CPU seconds. A restart file containing calculated displacement solution vectors was translated from binary to ASCII format, transferred using NASNET to the Langley CSM VAX computer, and converted back to a binary restart file for local postprocessing. The output file generated on NAS is returned to Langley and transferred using LARCNET to the central computer site for microfiche (7 to 25 microfiche). The postprocessing of these results and the model verification task are performed on the CSM VAX computer system instead of the Langley CYBER computers because of the large memory requirements.

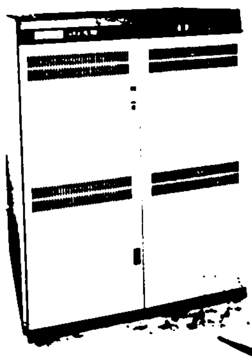
Significance:
The NAS CRAY-2 computer system is the <u>only</u> machine that has the memory and disk space to solve routinely the large structural models developed to support verification of the SRB. These agency-critical analyses have provided a better estimate of the computational requirements (hardware and software) needed to analyze large finite element models of realistic structures (flight hardware). In addition, the mechanisms developed to provide routine remote access to NAS have contributed to the requirements definition of Langley's local area network.

Future Plans:
Perform structural analyses of the SRB in support of Marshall Space Flight Center SRM Redesign Team. Develop and implement the CSM testbed system on the NAS computer system for methods research and application studies.

Structural Analysis Code STAGS Operational on NAS Computer

Langley VAX 11/785

Model Preparation
and Verification,
Pre/Post-Processing

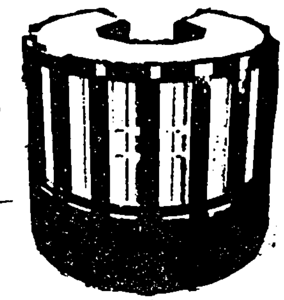


STAGS Data Sets (40Kbytes)

NASNET
(200Kbits/s)

STAGS Results (5 to 50Mbytes)

Ames NAS CRAY-2

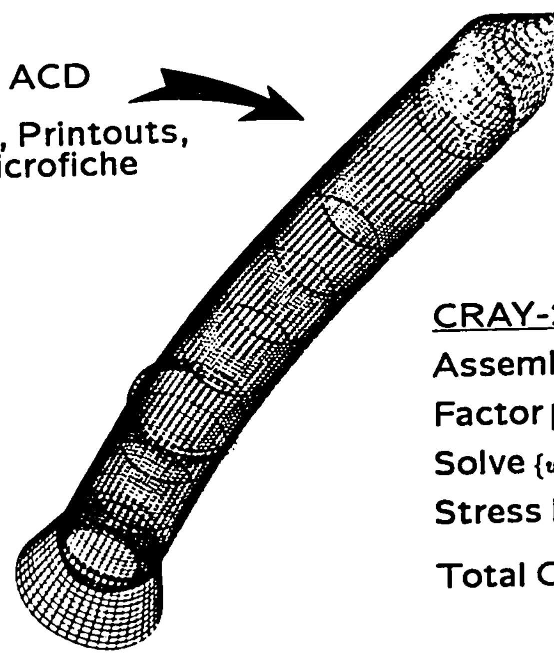


Number
Crunching

LARCNET
(256Kbits/s)

ACD

Plots, Printouts,
Microfiche



82974 Degrees-of-Freedom
506 Semi-Bandwidth
32 Million Words of Blank Common
60 Million Words of Main Memory
800Mbytes of Temporary Disk Space

<u>CRAY-2 Resources</u>

Assembly $[K]$ ... 101 sec.
Factor $[K]$ ... 685 sec.
Solve $\{u\} = [K]^{-1}\{P\}$ ... 45 sec.
Stress Recovery ... 22 sec.

Total CPU Time ... 853 sec.

GEODESIC COMPRESSION PANEL 3 PERCENT LIGHTER THAN AND MORE DAMAGE TOLERANT THAN STIFFENED SKIN COMPRESSION PANEL

Marshall Rouse
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Ext. 4505 September 1987
RTOP 505-63-11
Code RM WBS 55-1

Research Objective: To evaluate the performance of an advanced geodesic composite structural concept for commercial transport aircraft.

Approach: A geodesic compression panel was designed and fabricated with stiffeners oriented ±20° with respect to the longitudinal axis of the panel. The stiffeners were made of unidirectional tows of graphite fibers wrapped in graphite-epoxy woven material and secondarily bonded to the skin using a room-temperature-cure adhesive. The skin was fabricated with unidirectional graphite-epoxy plies in a pattern that simulates a filament-wound structure. The overall dimensions of the panel were 48 in. by 30 in. A photograph of the panel is shown on the left of the figure. The design loads for the panel are N_x=3,000 lb/in. and N_{xy}= 600 lb/in. which are representative of a transport fuselage. The loaded ends of the panel were enclosed in a potting material and the side of the panel were supported to prevent wide column buckling during loading. An undamaged specimen was loaded in compression to failure in the laboratory. A second specimen was subjected to low-speed impact damage and tested to failure to determine its residual strength.

Accomplishment Description: Test results suggest that this geodesic panel concept is more damage tolerant and more efficient than a conventional stiffened skin panel. The buckling (B) and failure (F) loads for the geodesic panel and a conventional stiffened skin panel are shown in the figure on the right as a function of weight. The results show that the geodesic panel is 3 percent lighter than the stiffened skin panel. Both panels had failure loads greater than the design conditions. The presence of low-speed impact damage did not influence the strength of the geodesic compression panel.

Significance: Although the geodesic panel failed at a lower load than the stiffened skin panel, the presence of low-speed impact damage did not influence the failure load of the geodesic panel which is not the case for conventional stiffened skin panels. The geodesic panel failed when the outer stiffeners separated from the skin along the unloaded edges of the panel. The outer stiffeners of the geodesic panel may not have been fully effective due to internal load redistribution which is a consequence of testing a relatively narrow nonprismatic cross section panel. It is believed that the geodesic panel concept would carry a higher load in a large-scale specimen or if this internal load redistribution were controlled or restrained.

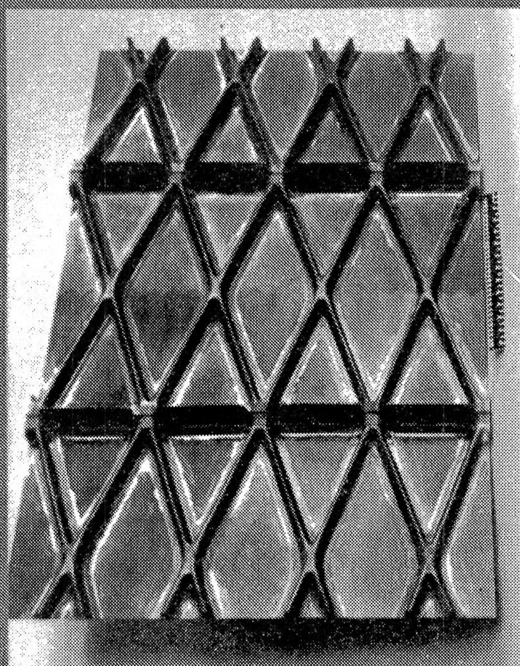
Future Plans: Conduct a detailed structural analysis of the geodesic panel to better understand the internal load redistribution and specimen behavior and to develop advanced structural concepts using filament wound and geodesic concepts.

GEODESIC COMPRESSION PANEL 3% LIGHTER THAN AND MORE DAMAGE TOLERANT THAN STIFFENED SKIN COMPRESSION PANEL

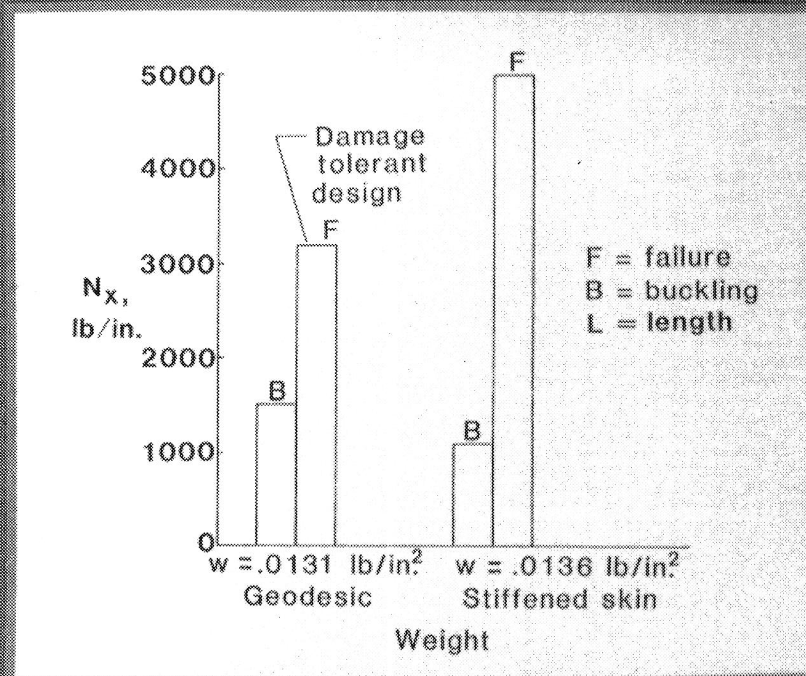
Design conditions:

N_x = 3,000 lb/in.

N_{xy} = 600 lb/in.



Geodesic compression panel



VIII PUBLICATIONS AND PRESENTATIONS

VIII PUBLICATIONS AND PRESENTATIONS

The FY 1987 accomplishments resulted in a number of publications and presentations. They are listed below as Formal Reports, High-Numbered Technical Memorandums, Contractor Reports, Journal Articles and Other Publications, Meeting Presentations, Technical Talks, Computer Programs, Tech Briefs, and Patents.

Formal Reports

1. Belvin, W. K.: Modeling of Joints for the Dynamic Analysis of Truss Structures. NASA TP-2661, May 1987
2. Daugherty, R. H.; and Stubbs, S. M.: Measurements of Flow Rate and Trajectory of Aircraft Tire-Generated Water Spray. NASA TP-2718, July 1987
3. Noor, A. K.; Andersen, C. M.; and Tanner, J. A.: Exploiting Symmetries in the Modeling and Analysis of Tires. NASA TP-2649, March 1987

High-Numbered Technical Memorandums

4. Anderson, M. S.; Williams, F. W.; Banerjee, J. R.; Durling, B. J.; Herstrom, C. L.; Kennedy, D.; and Warnaar, D. B.: User Manual for BUNVIS-RG: An Exact Buckling and Vibration Program for Lattice Structures, With Repetitive Geometry and Substructuring Options. NASA TM-87669, November 1986
5. Bales, K. S.: Structures and Dynamics Division Research and Technology Plans for FY 1987 and Accomplishments for FY 1986. NASA TM-89141, March 1987
6. Bostic, S. W.; and Fulton, R. E.: A Lanczos Eigenvalue Method on a Parallel Computer. NASA TM-89097, March 1987
7. Dorsey, J. T.; Stein, P. A.; and Bush, H. G.: Structural Design of an In-Line Bolted Joint for the Space Shuttle Rocket Motor Case Segments. NASA TM-89027, March 1987
8. Juang, J-N.; and Lim, K. G.: On the Eigenvalue and Eigenvector Derivatives of a General Matrix. NASA TM-89127, March 1987
9. Knight, N. F., Jr.: Nonlinear Shell Analyses of the SRB/ETA Ring Interface. NASA TM-89164, July 1987
10. Lotts, C. G.; Greene, W. H.; McCleary, S. L.; Knight, N. F., Jr.; Paulson, S. S.; and Gillian, R. E.: Introduction to the Computational Structural Mechanics Testbed. NASA TM-89096, September 1987
11. McGowan, D. M.; and Lake, M. S.: Experimental Evaluation of Small-Scale Erectable Truss Hardware. NASA TM-89068, June 1987
12. Mikulas, M. M., Jr.; and Bush, H. G.: Design, Construction and Utilization of a Space Station Assembled from 5-Meter Erectable Struts. NASA TM-89043, October 1986
13. Thurston, G. A.: A Parallel Solution for the Symmetric Eigenproblem. NASA TM-89082, January 1987

Contractor Reports

14. Adams, L. R.: Design, Development and Fabrication of a Deployable/Retractable Truss Beam Model for Large Space Structures Application. NASA CR-178287, June 1987 (NAS1-18013, Astro Aerospace Corporation)

15. Dodge, R. N.; and Clark, S. K.: Heat Generation in Aircraft Tires Under Yawed Rolling Conditions. NASA CR-4080, July 1987 (NSG-1607, The University of Michigan)

16. Edighoffer, H. H.: Dynamic and Thermal Response Finite Element Models of Multi-Body Space Structural Configurations. NASA CR-178289, April 1987 (NAS1-17210, Edighoffer, Inc.)

17. Gronet, M. J.; Pinson, E. D.; Voqui, H. L.; Crawley, E. F.; and Everman, M. R.: Preliminary Design, Analysis, and Costing of a Dynamic Scale Model of the NASA Space Station. NASA CR-4068, July 1987 (NAS1-18229, Lockheed Missiles & Space Company, Inc.)

18. Hedgepeth, J. M.: Evaluation of Pactruss Design Characteristics Critical to Space Station Primary Structure. NASA CR-178171, February 1987 (NAS1-17536, Astro Aerospace Corporation)

19. Hedgepeth, J. M.; and Miller, R. K.: Structural Concepts for Large Solar Concentrators. NASA CR-4075, June 1987 (NAS1-17536, Astro Aerospace Corporation)

20. Pifko, A. B.; Winter, R.; and Ogilvie, P. L.: DYCAST - A Finite Element Program for the Crash Analysis of Structures. NASA CR-4040, January 1987 (NAS1- 13148, Grumman Corporation)

21. Rankin, C. C.; Stehlin, P.; and Brogan, F. A.: Enhancements to the STAGS Computer Code. NASA CR-4000, November 1986 (NAS1-16723, Lockheed Missiles & Space Company, Inc., Palo Alto Research Laboratories)

22. Reddy, J. N.; and Liu, C. F.: A Higher-Order Theory for Geometrically Nonlinear Analysis of Composite Laminates. NASA CR-4056, March 1987 (NAG1-459, Virginia Polytechnic Institute and State University

23. Sesak, J. R.; Gronet, M. J.; and Marinos, G. M.: Passive Stabilization for Large Space Systems. NASA CR-4067, April 1987 (NAS1-17660, Lockheed Missiles & Space Company, Inc.)

Journal Articles and Other Publications

24. Anderson, M. S.; and Williams, F. W.: BUNVIS-RC: Exact Frame Buckling and Vibration Program, With Repetitive Geometry and Substructuring. Journal of Spacecraft and Rockets, Volume 24, No. 4, July-August 1987, p. 353-361

25. Bainum, P. M.; Woodard, S. E.; and Juang, J-N.: Optimal Control Laws for Orbiting Tethered Platform Systems. Journal of the Astronautical Sciences, Volume 35, No. 2, April-June 1987, p. 135-153

26. Belvin, W. K.; and Edighoffer, H. H.: Dynamic Analysis and Experiment Methods for a Generic Space Station Model. Journal of Spacecraft and Rockets, Volume 24, No. 3, May-June 1987, p. 270-276

27. Bostic, S. W.; and Fulton, R. E.: Implementation of the Lanczos Method for Structural Vibration Analysis on a Parallel Computer. Computers and Structures, Volume 25, No. 3, 1987, p. 395-403

28. Darbhamulla, S. P.; Razzaq, Z.; and Storaasli, O. O.: Concurrent Processing for Nonlinear Analysis of Hollow Rectangular Structural Sections. Engineering With Computers, Volume 2, No. 4, 1987, p. 209-217

29. Fasanella, E. L.; Widmayer, E. L.; and Robinson, M. P.: Structural Analysis of the Controlled Impact Demonstration of a Jet Transport Airplane. Journal of Aircraft, Volume 24, No. 4, April 1987, p. 274-280

30. Horta, L. G.; Juang, J-N.; and Junkins, J. L.: A Sequential Linear Optimization Approach for Controller Design. Journal of Guidance, Control, and Dynamics, Volume 9, No. 6, November-December 1986, p. 699-703

31. Juang, J-N.; Turner, J. D.; and Chun, H. M.: Closed-Form Recursive Formula for an Optimal Tracker With Terminal Constraints. Journal of Optimization Theory and Application, Volume 51, No. 2, November 1986, p. 133

32. Juang, J-N.: Mathematical Correlation of Modal-Parameter-Identification Methods Via System-Realization Theory. The International Journal of Analytical and Experimental Modal Analysis. Volume 2, No. 1, January 1987, p. 1-18

33. Juang, J-N.; and Horta, L. G.: Effects of Atmosphere on Slewing Control of a Flexible Structure. Journal of Guidance, Control, and Dynamics, Volume 10, No. 4, July-August 1987, p. 387-392

34. McComb, H. G., Jr.; Thomson, R. G.; and Hayduk, R. J.: Structural Dynamics Research in a Full-Scale Transport Aircraft Crash Test. Journal of Aircraft, Volume 24, No. 7, July 1987, p. 447-453

35. Nemeth, M. P.: Importance of Anisotropy on Buckling of Compression-Loaded Symmetric Composite Plates. AIAA Journal, Volume 24, No. 11, November 1986, p. 1831-1835

36. Noor, A. K.; Storaasli, O. O.; and Fulton, R. E.: Algorithms and Software Development. In Finite Element Handbook, H. Kardestuncer, ed., McGraw-Hill, 1987, p. 230-233

37. Noor, A. K.; Storaasli, O. O.; and Fulton, R. E.: Modern Computing Systems. In Finite Element Handbook, H. Kardestuncer, ed., McGraw-Hill, 1987, p. 209- 230

38. Pappa, R. S.; and Juang, J-N.: Studies of Modal Identification Performance Using Hybrid Data. The International Journal of Analytical and Experimental Modal Analysis, Volume 2, No. 2, April 1987, p. 99-108

39. Post, D.; Czarnek, R.; and Joh, D.: Shear Strains in a Graphite-PEEK Beam by Moire Interferometry With Carrier Fringes. In Optical Methods in Composites, Proceedings of the 1986 SEM Fall Conference on Experimental Mechanics, November 2-5, 1986, Keystone, CO, pp. 159-164 (Sponsored in part by NASA Grant NAG1-481)

40. Rasdorf, W. J.; and Storaasli, O. O.: Educational Fundamentals of Computer-Aided Engineering. International Journal of Applied Engineering Education, Volume 3, No. 3, 1987, p. 247-254

41. Stein, M.; and Jegley, D. C.: Effects of Transverse Shearing on Cylindrical Bending, Vibration, and Buckling of Laminated Plates. AIAA Journal, Volume 25, No. 1, January 1987, p. 123-129

42. Storaasli, O. O.; and Bergan, P. G.: Nonlinear Substructuring Method for Concurrent Processing Computers. AIAA Journal, Volume 25, No. 6, June 1987, p. 871-876

43. Storaasli, O. O.; Ransom, J. B.; and Fulton, R. E.: Structural Dynamic Analysis on a Parallel Computer: The Finite Element Machine. Computers and Structures, Vol. 26, No. 4, 1987, p. 551-559

44. Yager, T. J.; and Davis, P. A.: NASA Langley's Unique Aircraft Landing Dynamics Facility. Flight Safety Digest, Volume 5, No. 11, November 1986, p. 5-9

Meeting Presentations

45. Belvin, W. K.; and Edighoffer, H. H.: 15-Meter Hoop-Column Antenna Dynamics: Test and Analysis. Presented at the First NASA/DOD CSI Technology Conference, November 18-21, 1986, Norfolk, Virginia. In NASA CP-2447, Part 1, p. 167-185

46. Belvin, W. K.; Edighoffer, H. H.; and Herstrom, C. L.: Quasi-Static Shape Adjustment of a 15-Meter Diameter Space Antenna. Presented at the AIAA/ASME, et al., 28th Structures, Structural Dynamics and Materials Conference, April 6-8, 1987, Monterey, California. AIAA Paper No. 87-0869-CP

47. Boitnott, R. L.; Fasanella, E. L.; Carden, H. D.; and Calton, L. E.: Impact Response of Composite Fuselage Frames. Presented at the SAE General Aviation Aircraft Meeting and Exposition, April 28-May 1, 1987, Wichita, Kansas. SAE Paper No. 871009

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51. Chun, H. M.; Turner, J. D.; and Juang, J-N.: Frequency-Shaped Large-Angle Maneuvers. Presented at the AIAA 25th Aerospace Sciences Meeting, January 12-15, 1987, Reno, Nevada. AIAA Paper No. 87-0174

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53. Cooper, P. A.; Young, J. W.; and Sutter, T. R.: Multidisciplinary Analysis of Actively Controlled Large Flexible Spacecraft. Presented at the First NASA/DOD CSI Technology Conference, November 18-21, 1986, Norfolk, Virginia. In NASA CP-2447, Part 1, p. 495-514

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55. Daugherty, R. H.; and Stubbs, S. M.: Flow Rate and Trajectory of Water Spray Produced by an Aircraft Tire. Presented at the SAE 1986 Aerospace Technology Conference and Exposition, October 13-16, 1986, Long Beach, California. SAE Paper No. 86-1626

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57. Ghaemmaghami, P.; and Juang, J-N.: A Controller Design for Three-Body Large Angle Maneuvers. Presented at the International Symposium on the Mathematical Theory of Networks and Systems (MTNS), June 15-19, 1987, Phoenix, Arizona. Proceedings pending

58. Ghaemmaghami, P.: Optimum Suspension Design for Space Structure Experiments. Presented at the Sixth VPI&SU/AIAA Symposium on Dynamics and Control of Large Space Structures, June 29-July 1, 1987, Blacksburg, Virginia

59. Hanks, B. R.: Some Practical Aspects of Flexible Structure Control. Presented at the Sixth VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, June 29-July 1, 1987, Blacksburg, Virginia. Proceedings Pending

60. Horta, L. G.; Walsh, J. L.; Horner, G. C.; and Bailey, J. P.: Analysis and Simulation of the Mast (COFS-I Flight Hardware). Presented at the First NASA/DOD CSI Technology Conference, November 18-21, 1986, Norfolk, Virginia. In NASA CP-2447, Part 1, p. 515-532

61. Huang, J-K.; Juang, J-N.; and Chen, C. W.: Single Mode Projection Filters for Identification and State Estimation of Flexible Structures. Presented at the AIAA Guidance, Navigation and Control Conference, August 17-19, 1987, Monterey, California. AIAA Paper No. 87-2387-CP

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16. Abstract

This paper presents the Objectives, FY 1988 Plans, Approach, and FY 1988 Milestones for the Structures and Dynamics Division's research programs. FY 1987 Accomplishments are presented where applicable. This information is useful in program coordination with other governmental organizations in areas of mutual interest.

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